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Marques et al.

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(54) **CAPACITIVE TOUCH SENSOR**

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See application file for complete search history.

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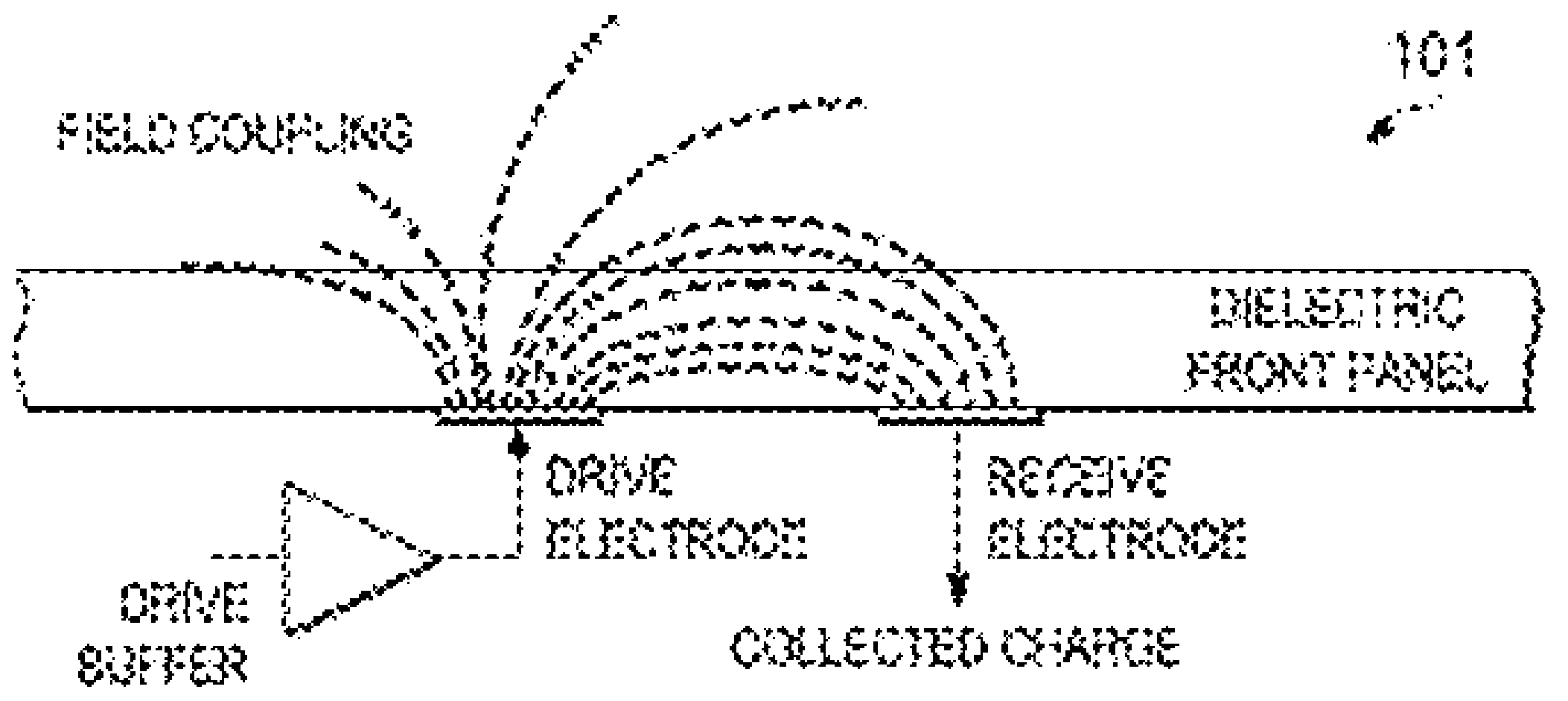
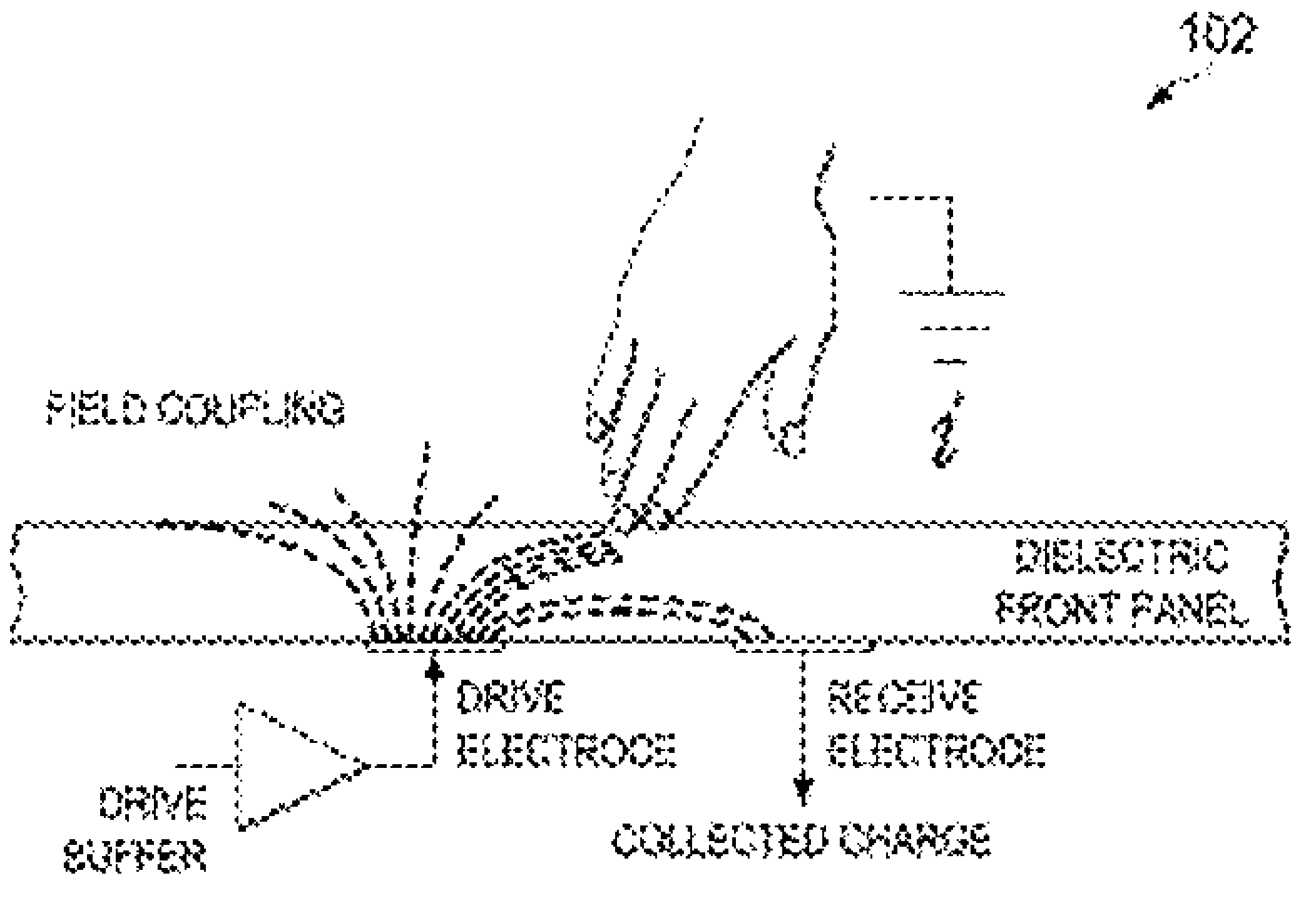
(74) *Attorney, Agent, or Firm* — Fish & Richardson P.C.

(57) **ABSTRACT**

A capacitive touch sensor is described. The touch sensor includes a sensor grid that includes a trace that has a trace start point and end point, is electrically conductive between the trace start point and the trace end point, is formed in one or more pairs of trace cells that each include a first trace cell and a second trace cell that is rotationally symmetrical to the first trace cell. The trace start point and the trace end point define a trace axis. A trace direction is defined from the trace start point to the trace end point. A trace-perpendicular direction is defined as being perpendicular to the trace direction. A segment of the trace that is formed in the first trace cell includes a first portion, a second portion, a third portion, a fourth portion, a fifth portion, a sixth portion, a seventh portion, and an eighth portion.

17 Claims, 14 Drawing Sheets





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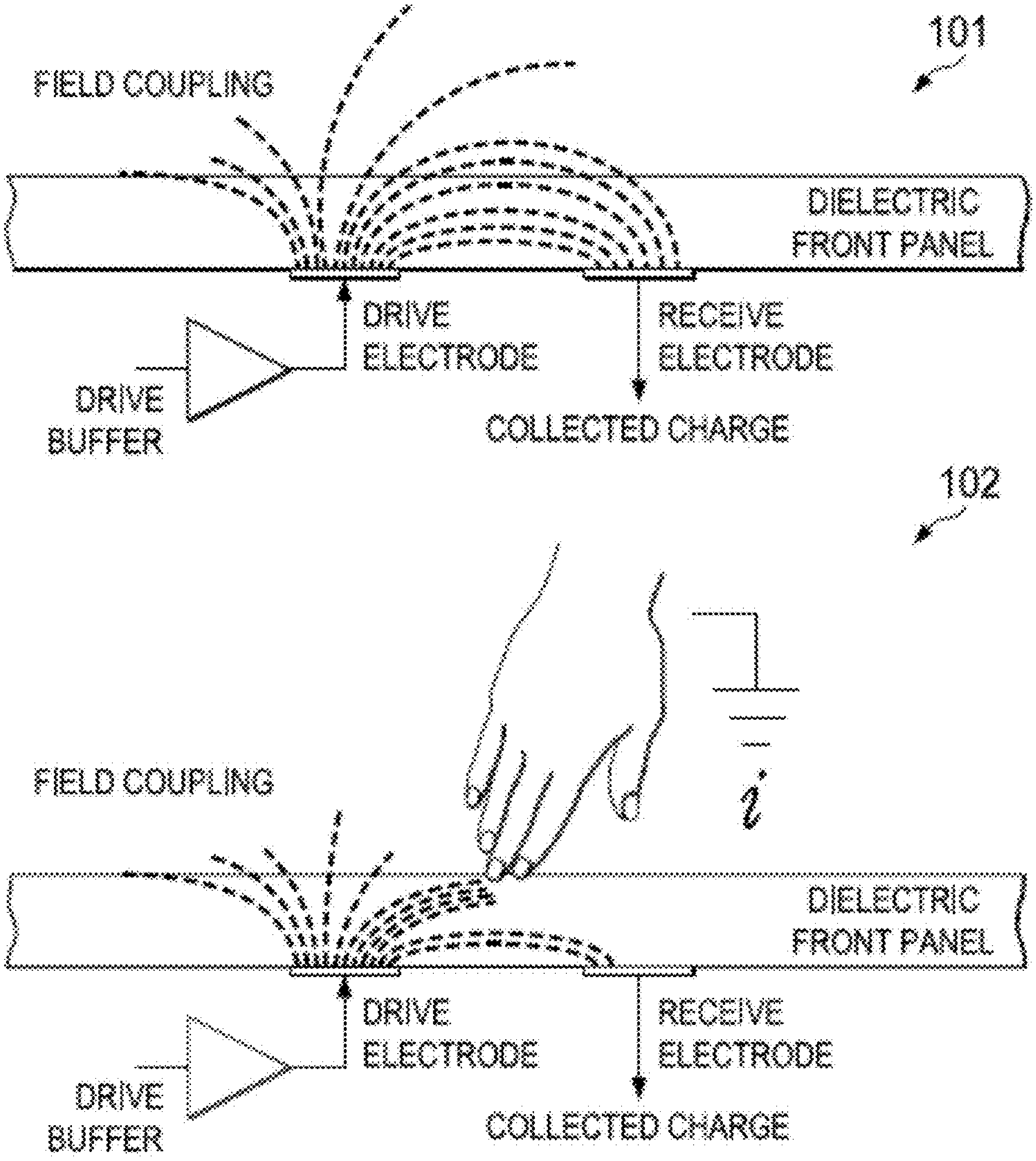
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FIELD COUPLING
DIELECTRIC FRONT PANEL
DRIVE ELECTRODE
RECEIVE ELECTRODE
DRIVE BUFFER
COLLECTED CHARGE
102
FIELD COUPLING
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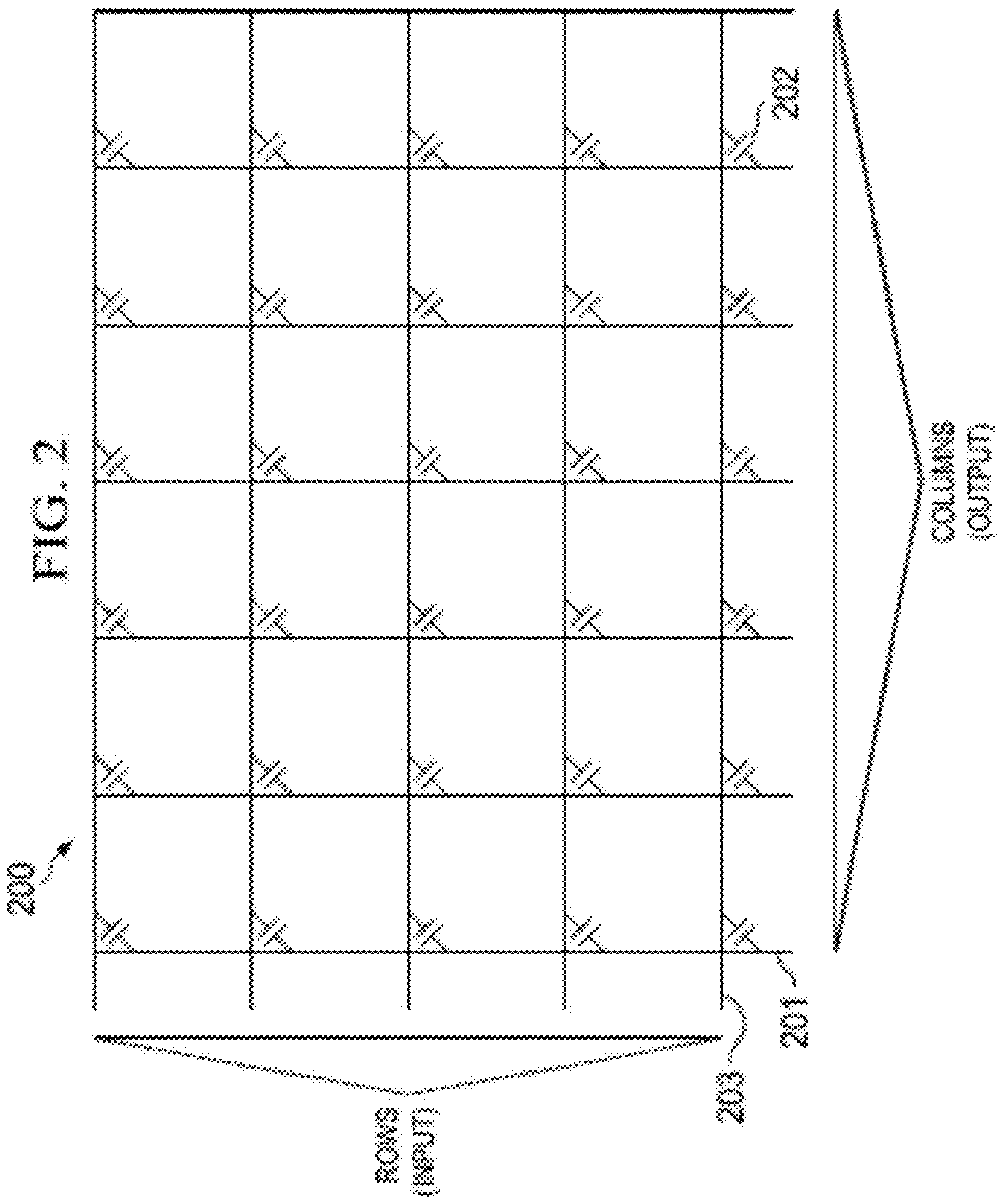
DRIVE BUFFER
COLLECTED CHARGE

FIG. 1

FIG. 2



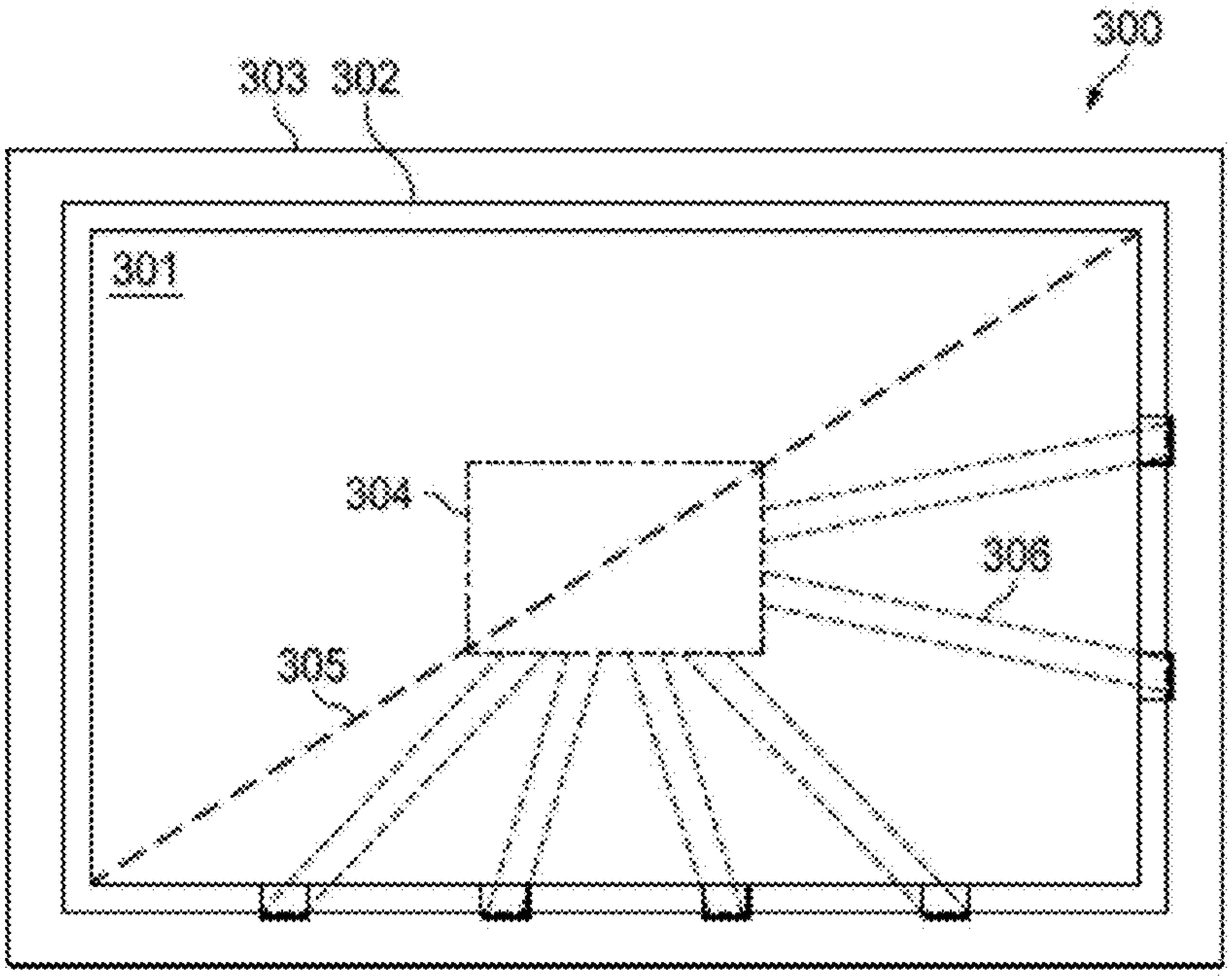


FIG. 3A

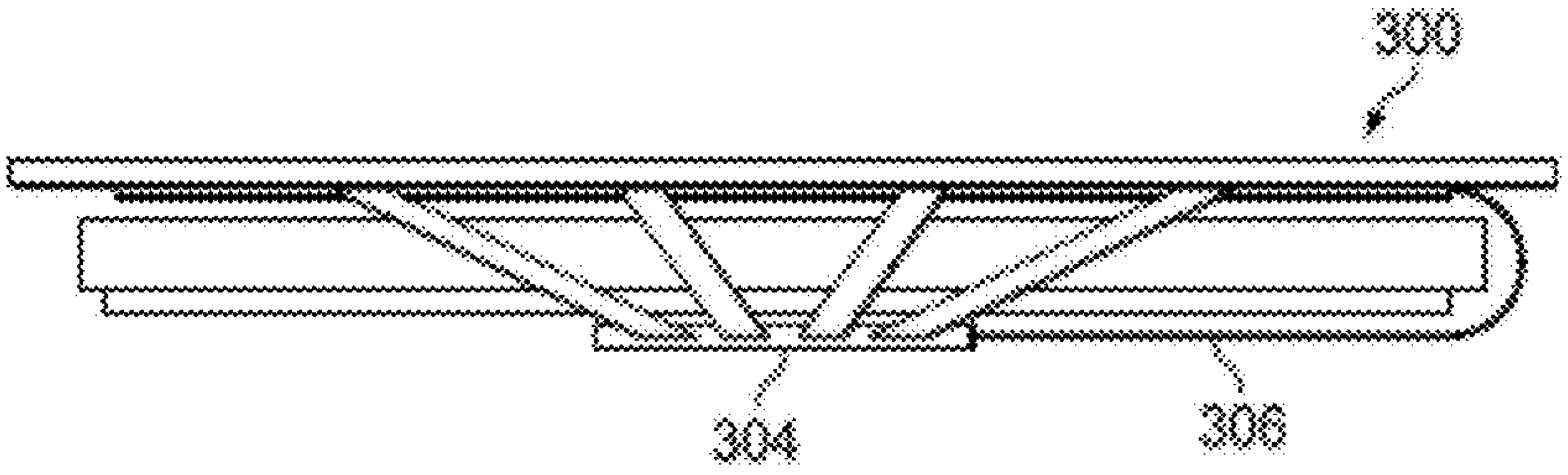
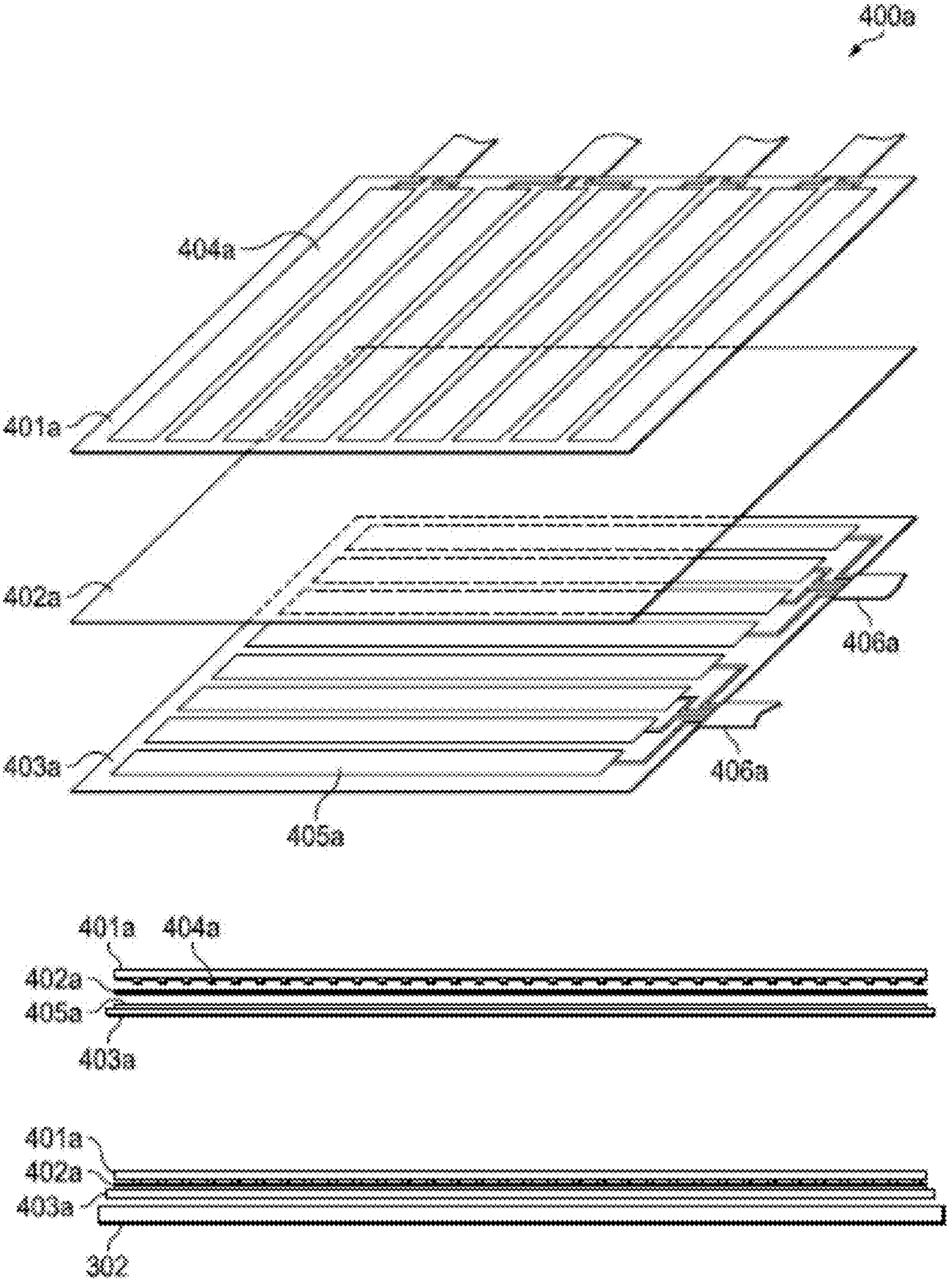


FIG. 3B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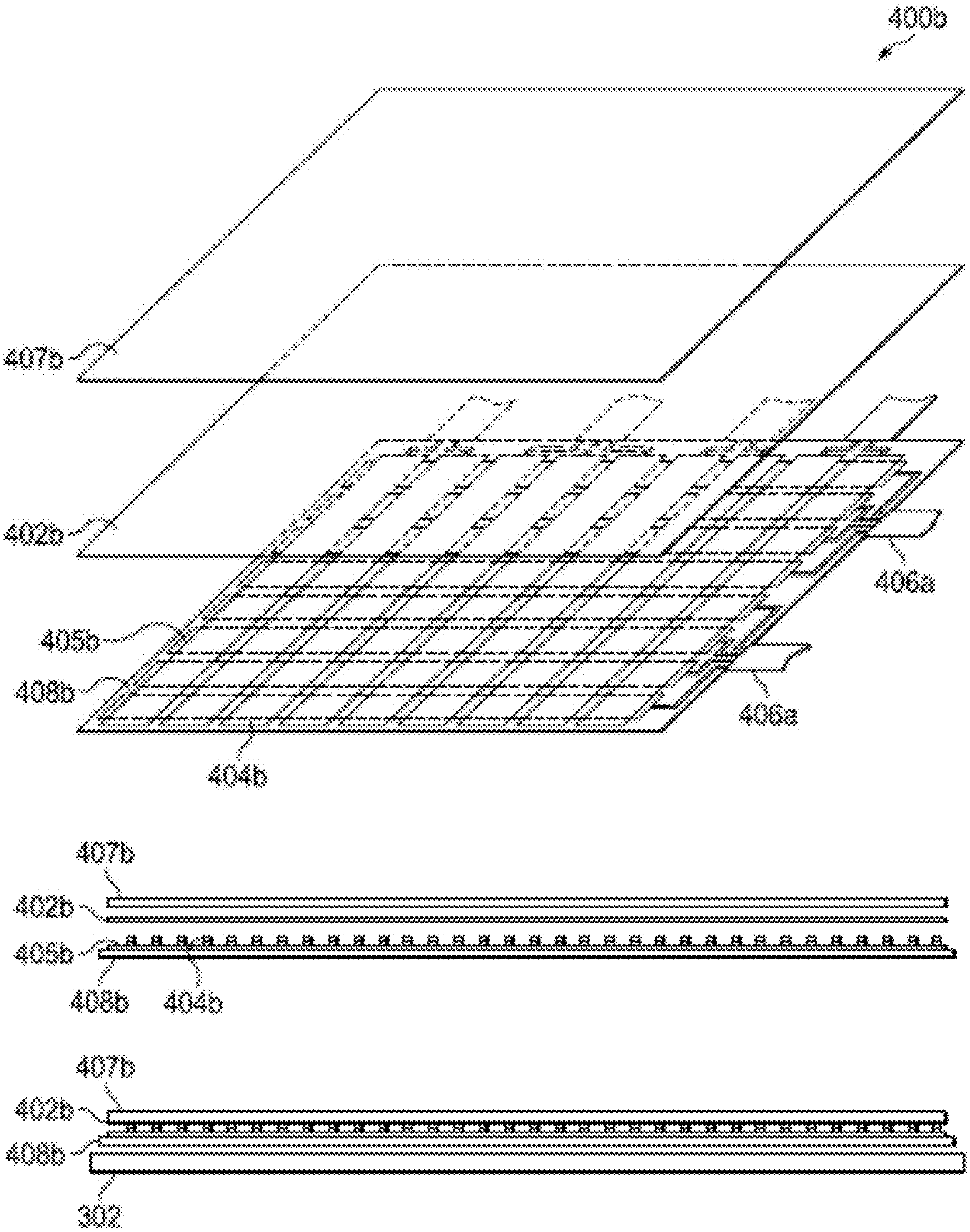
302

FIG. 4A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408b
302

FIG. 4B

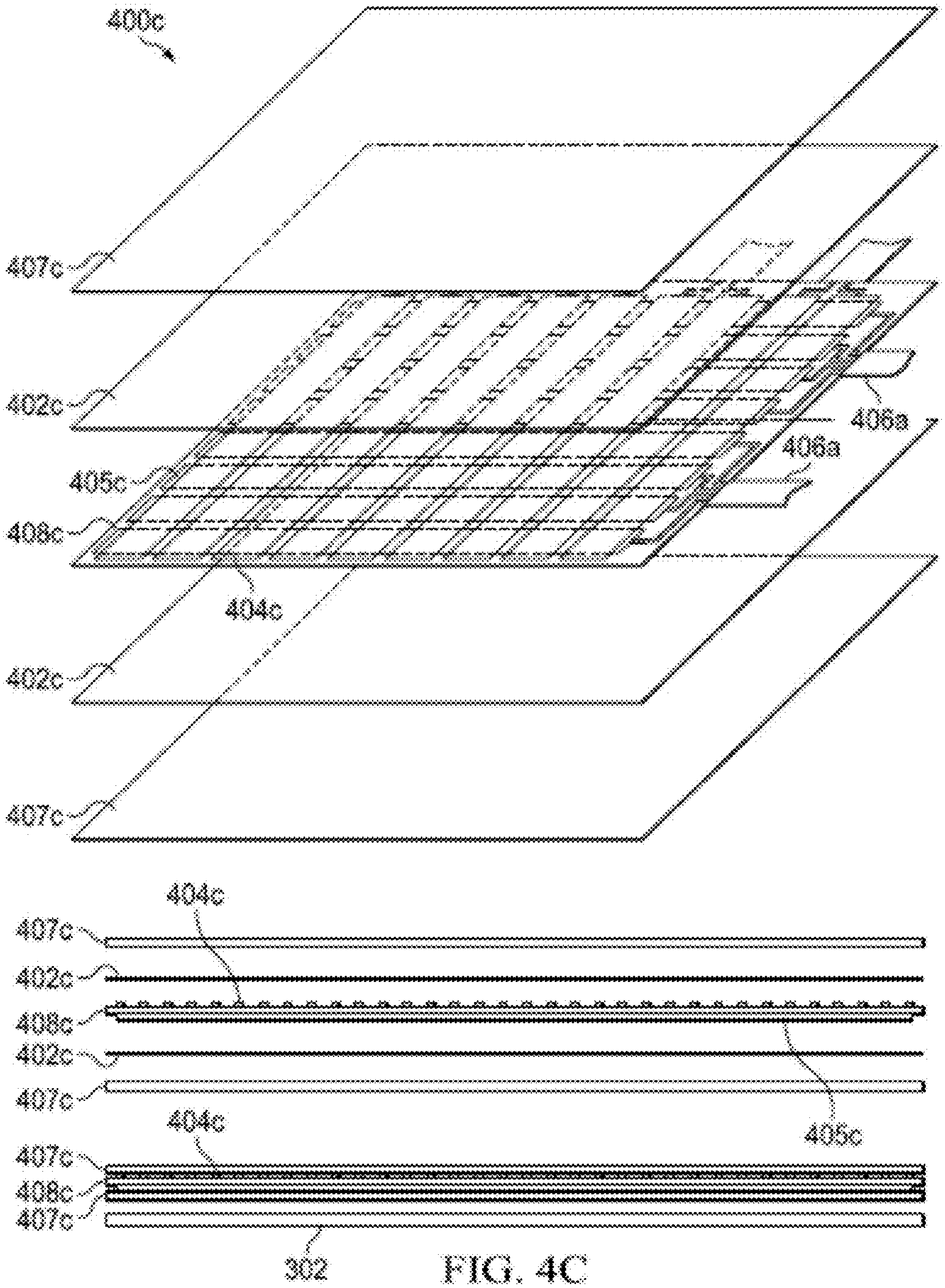
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FIG. 4C

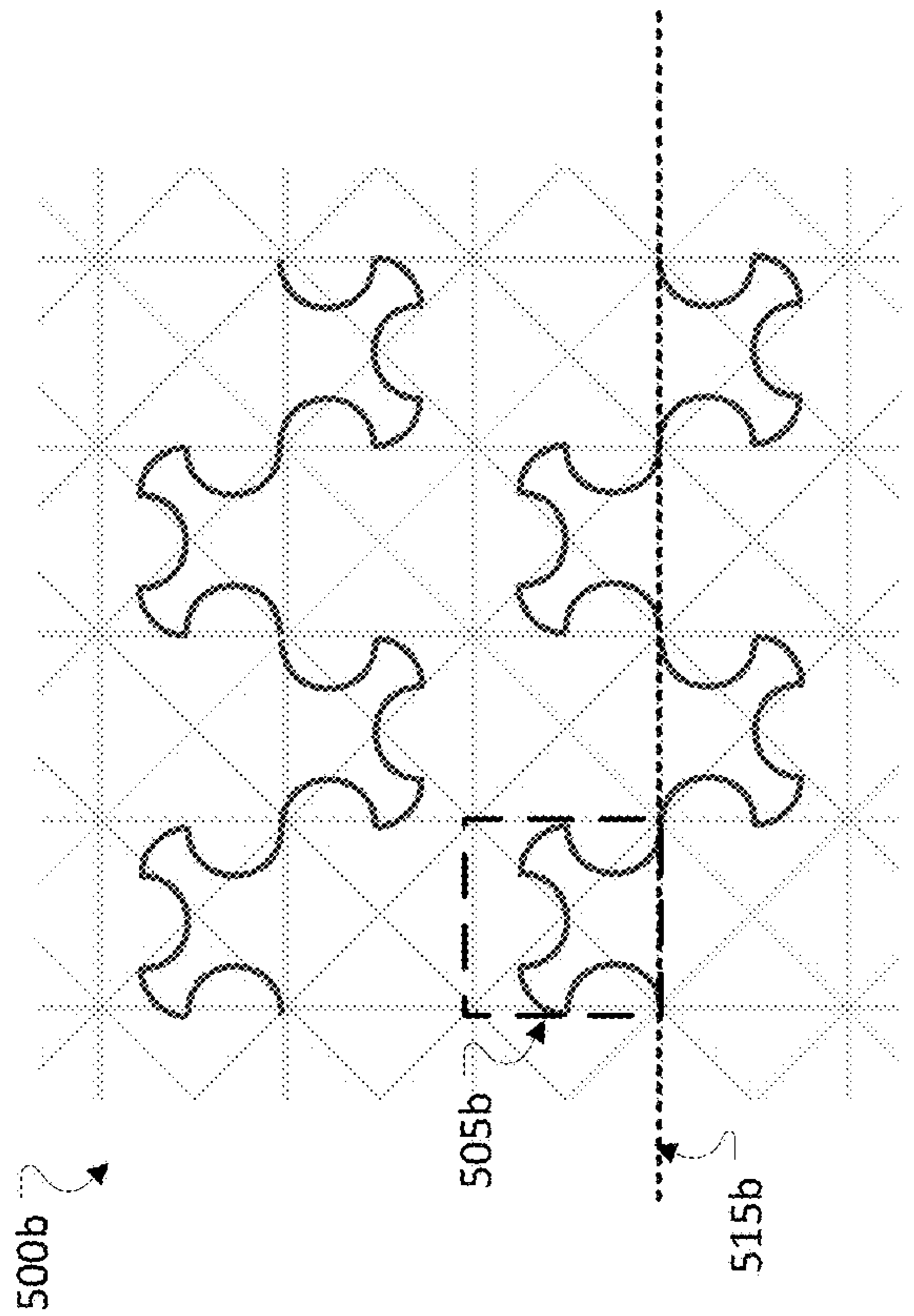

FIG. 5B

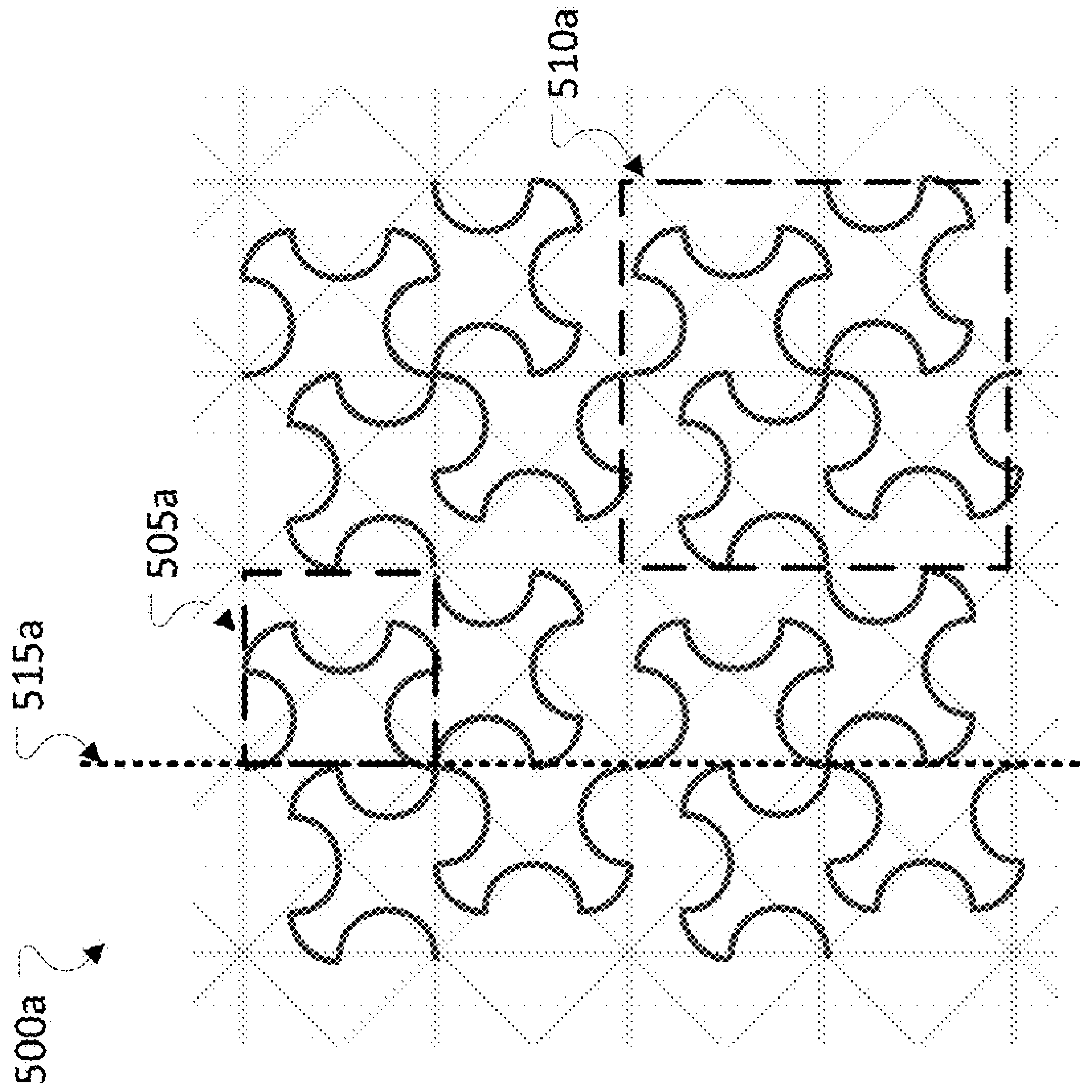

FIG. 5A

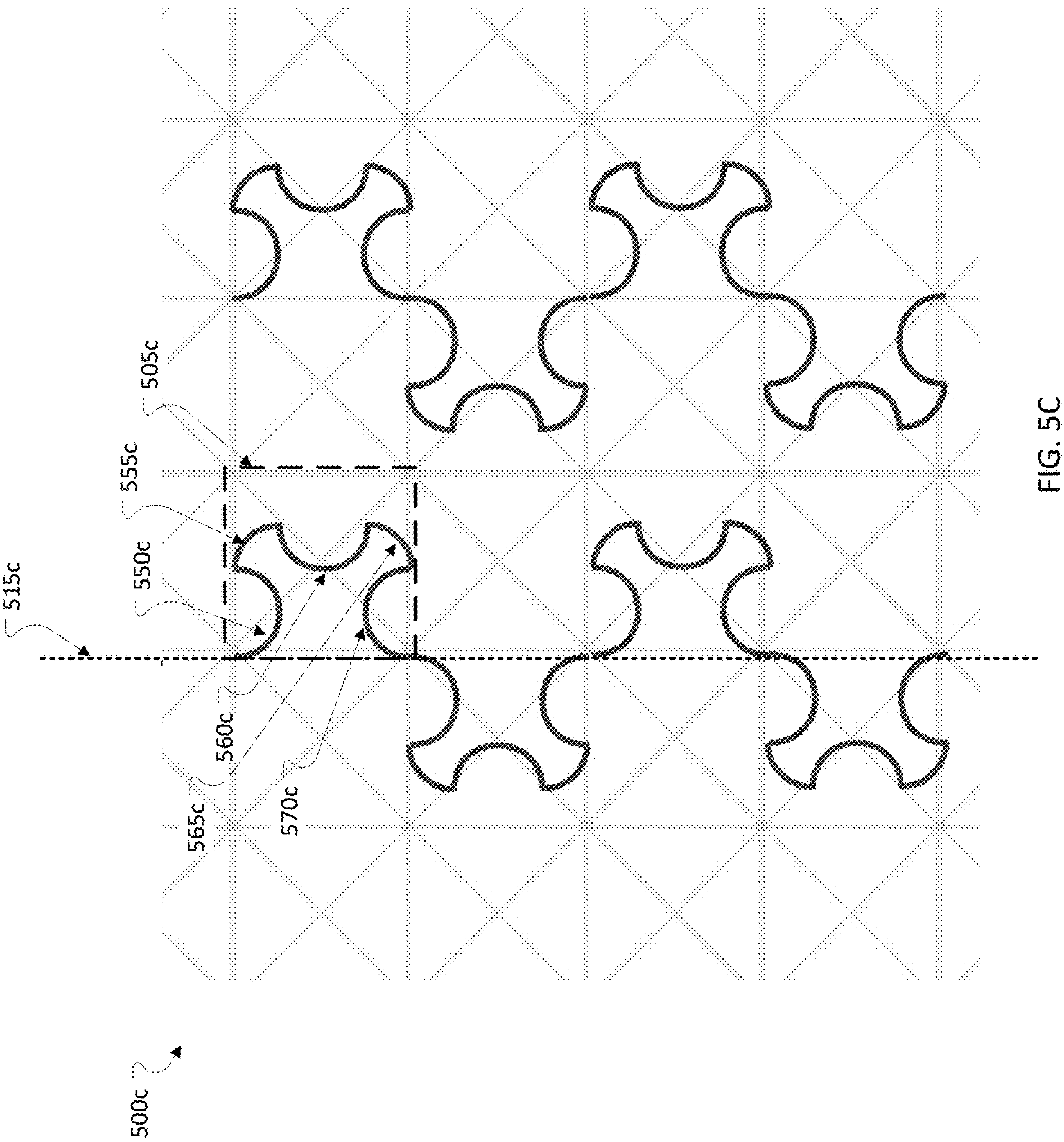

FIG. 5C

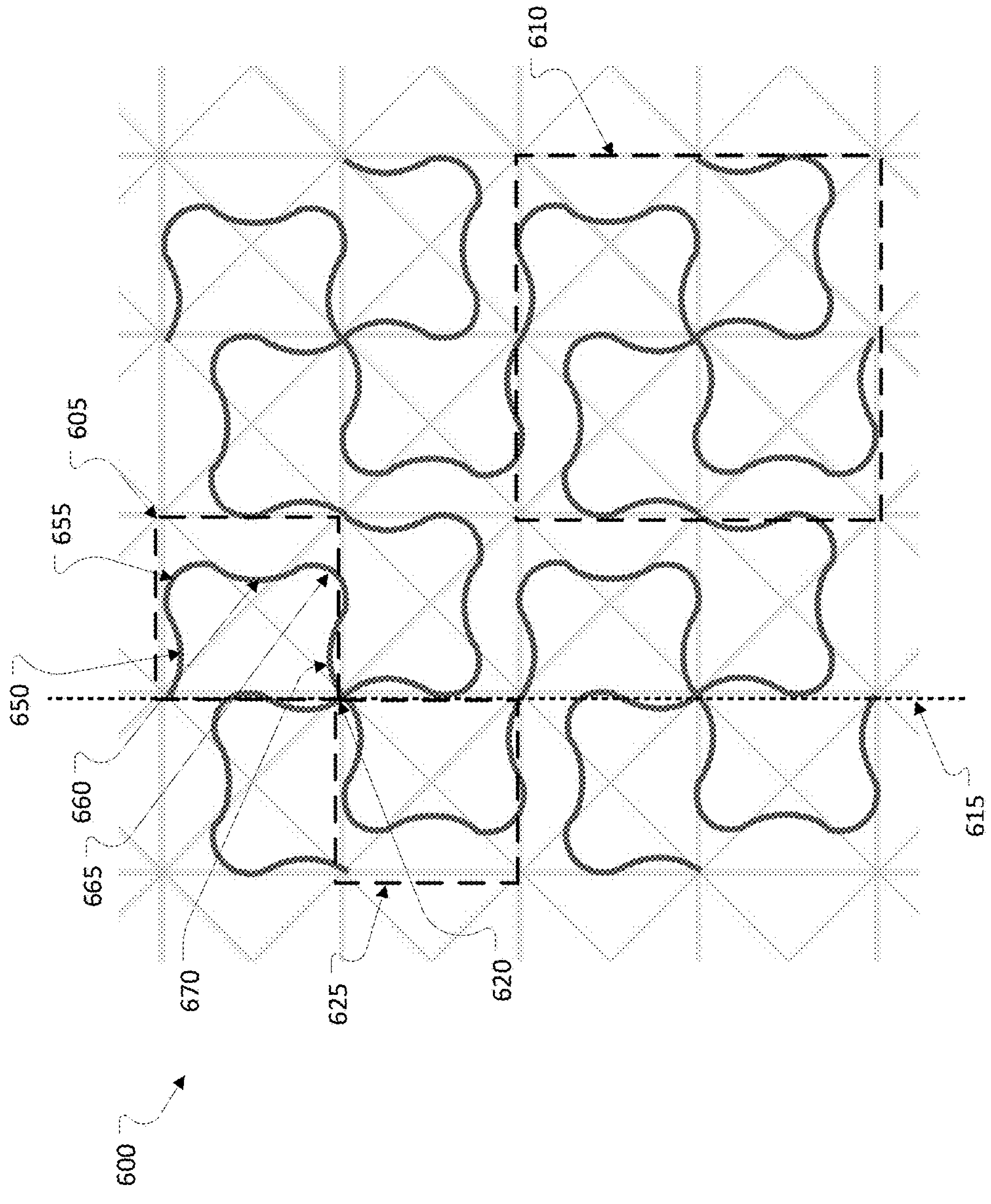

FIG. 6

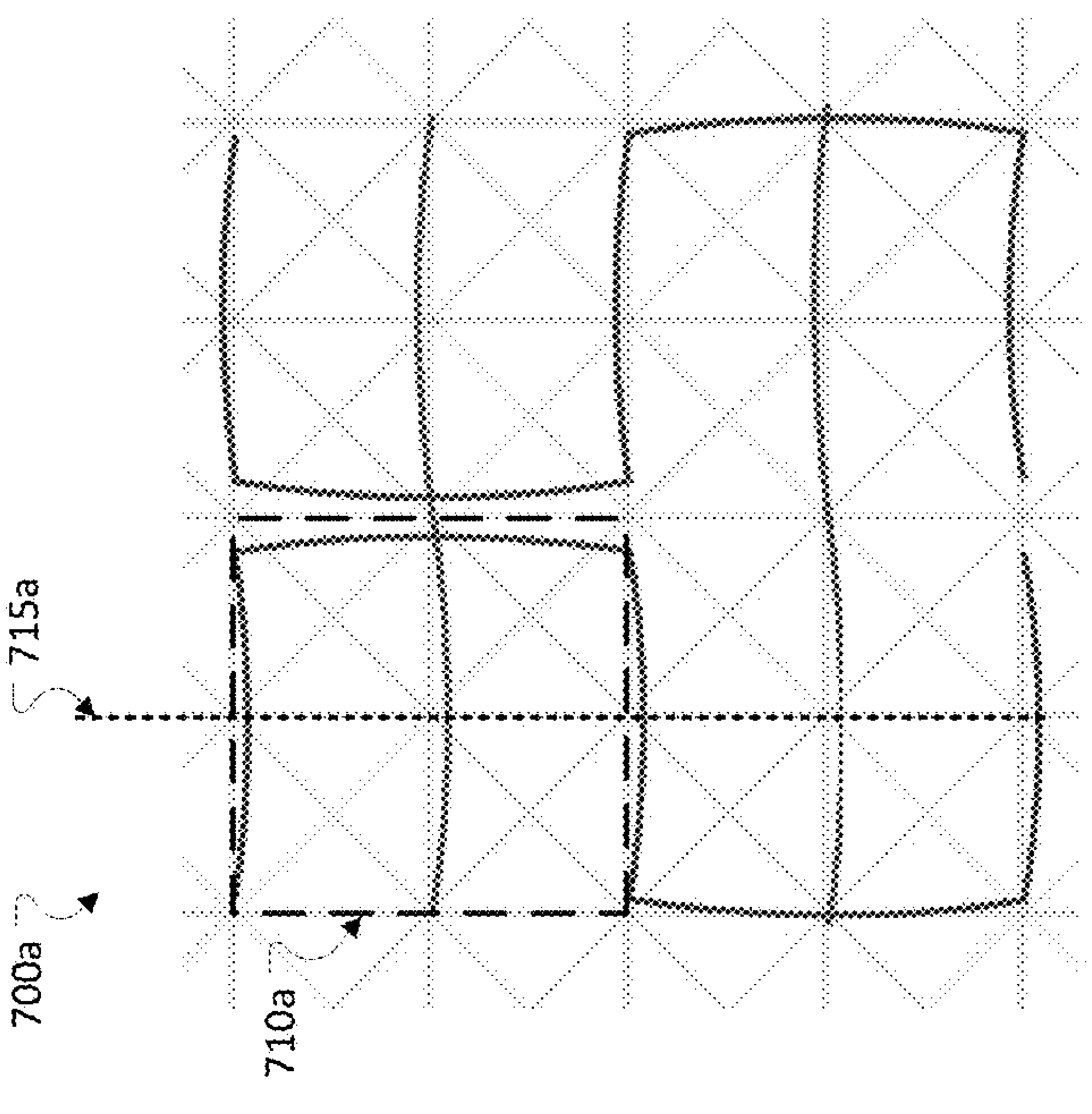

FIG. 7A

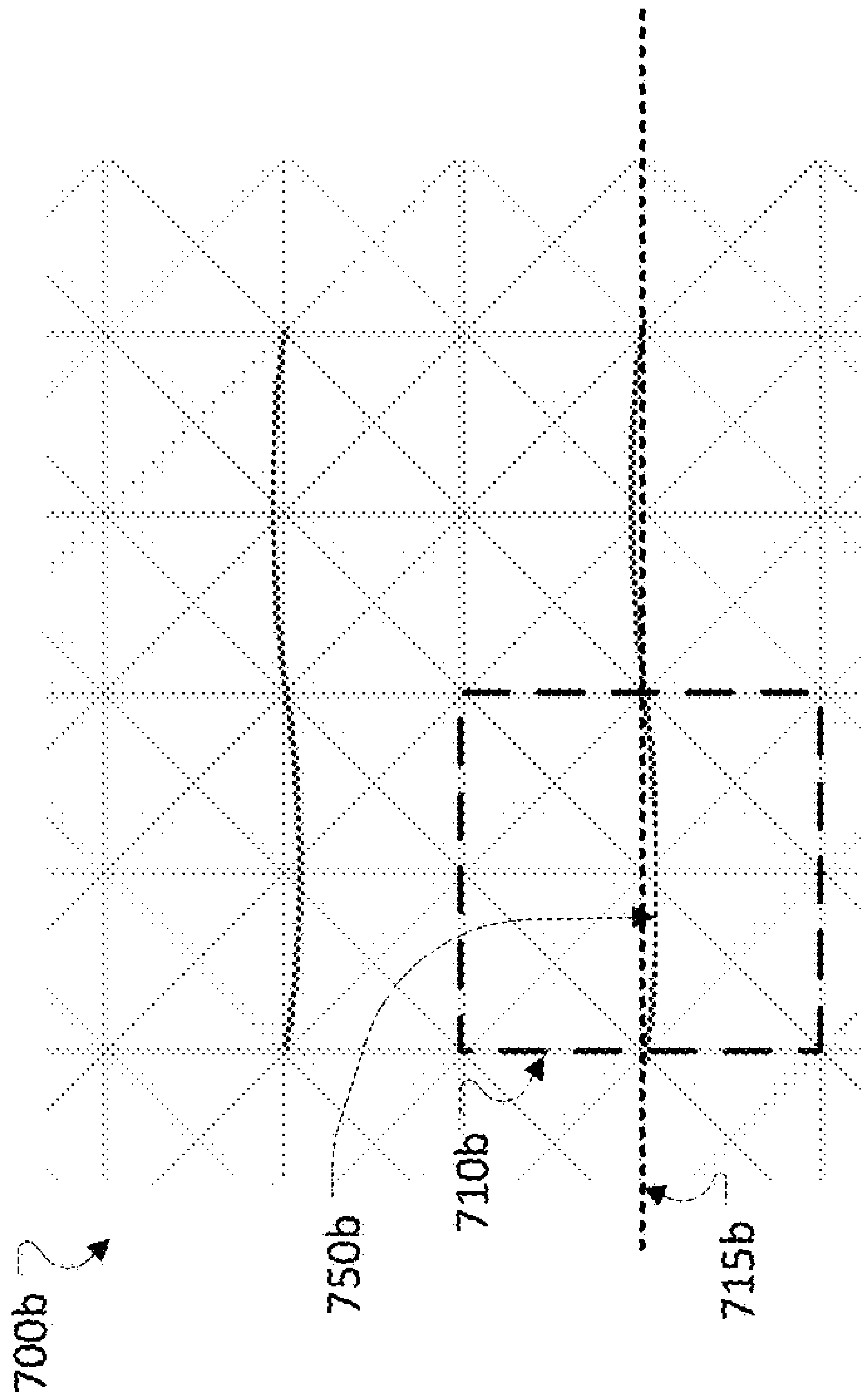

FIG. 7B

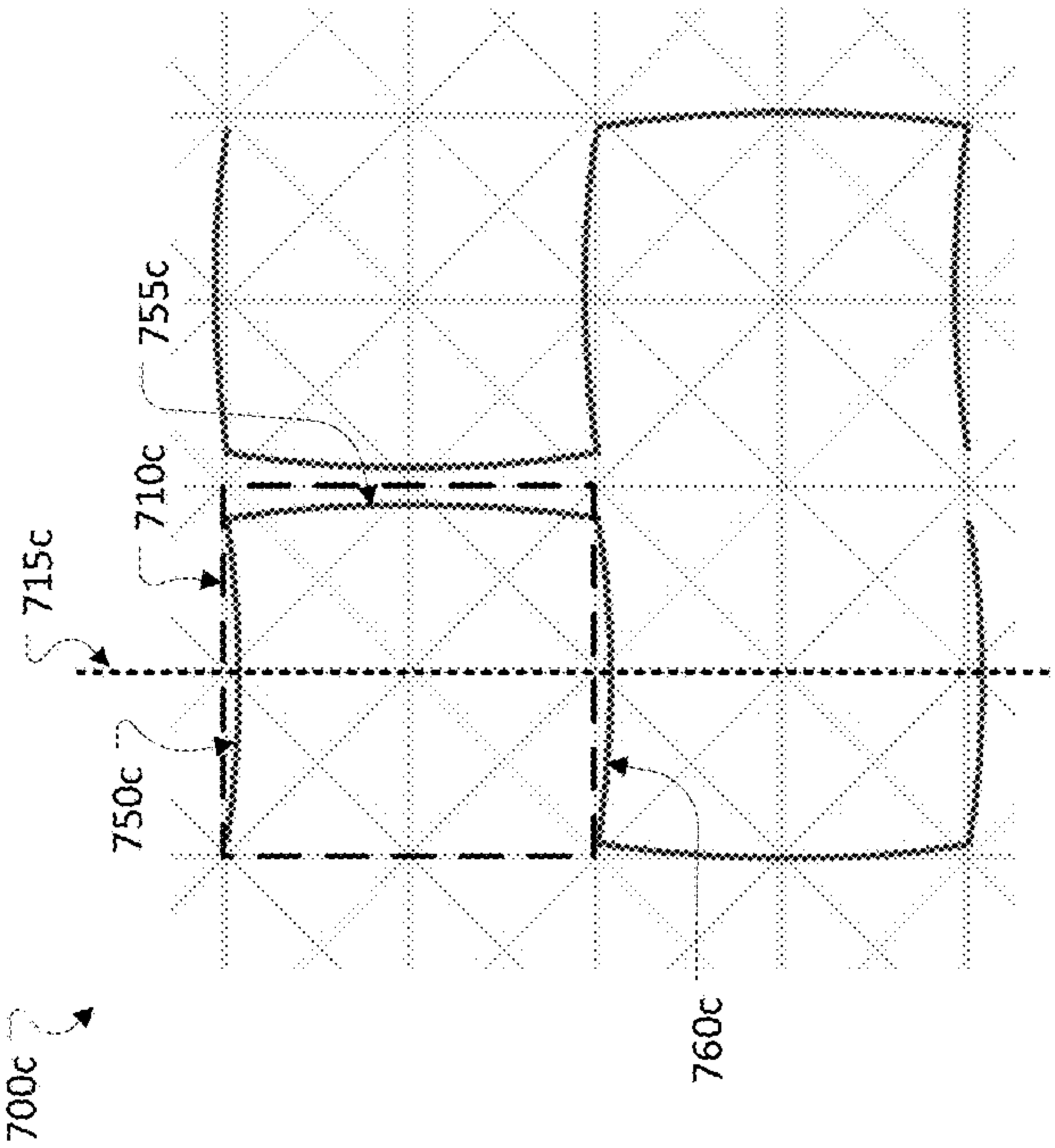

FIG. 7C

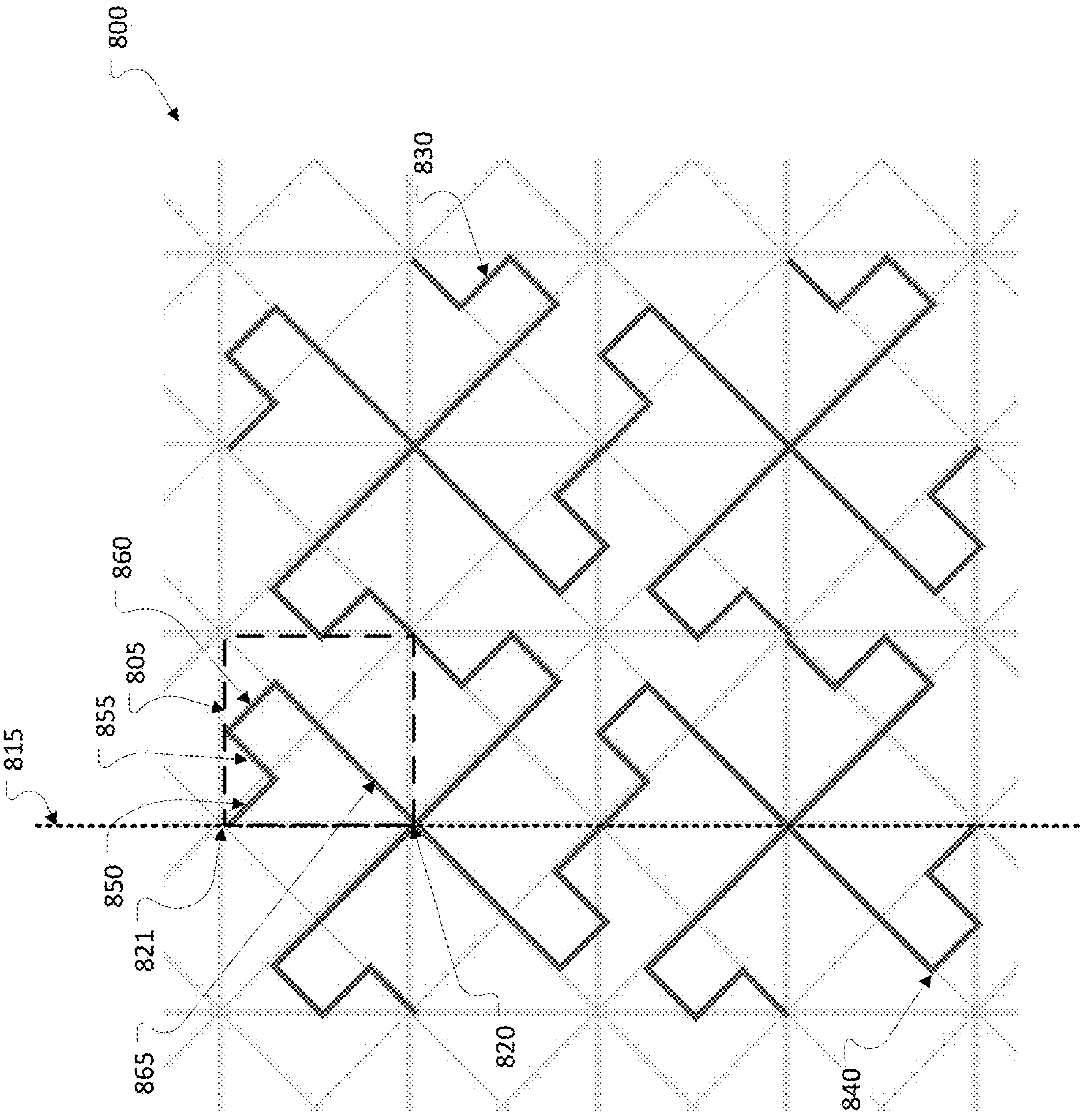

FIG. 8

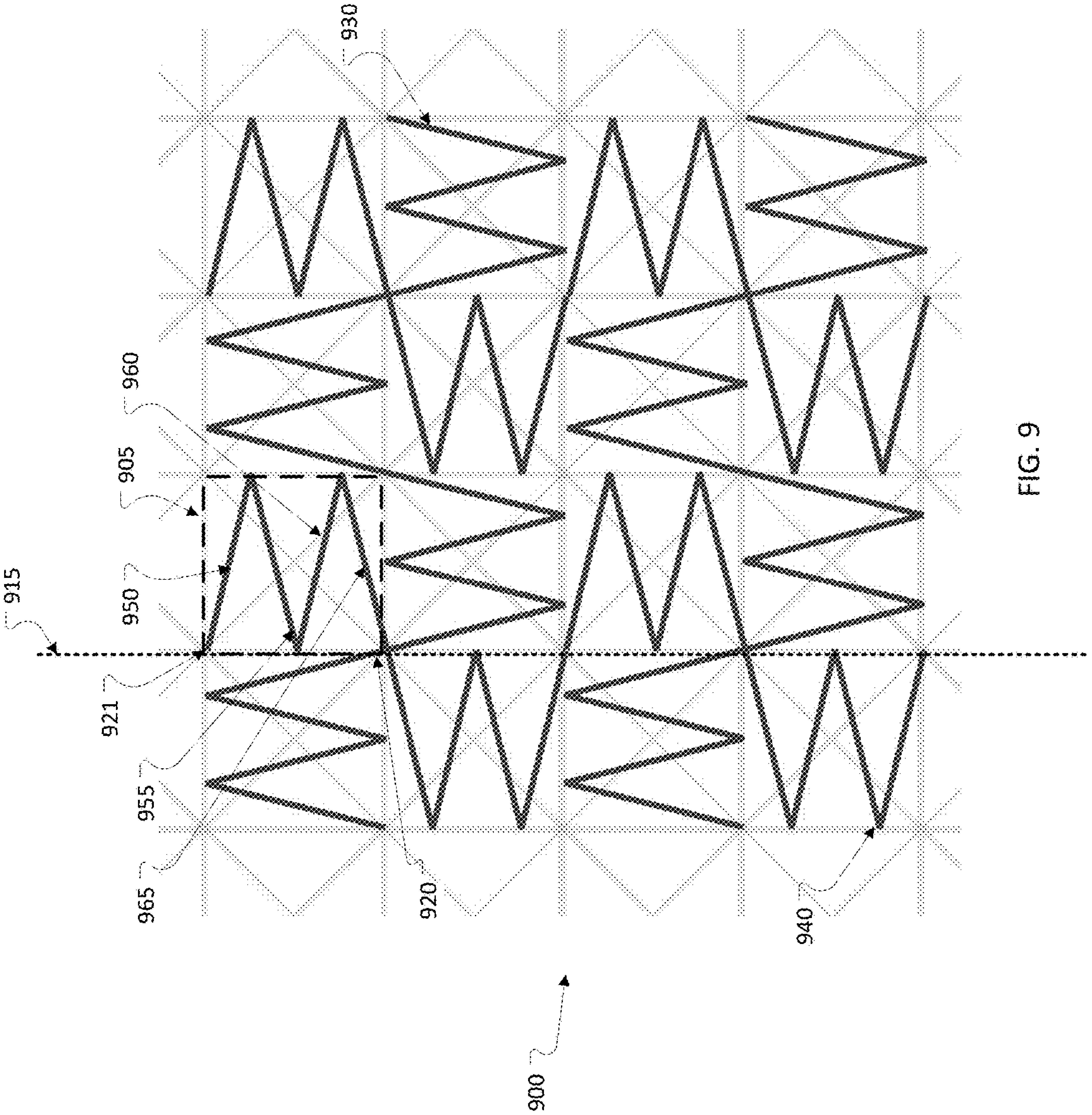

FIG. 9

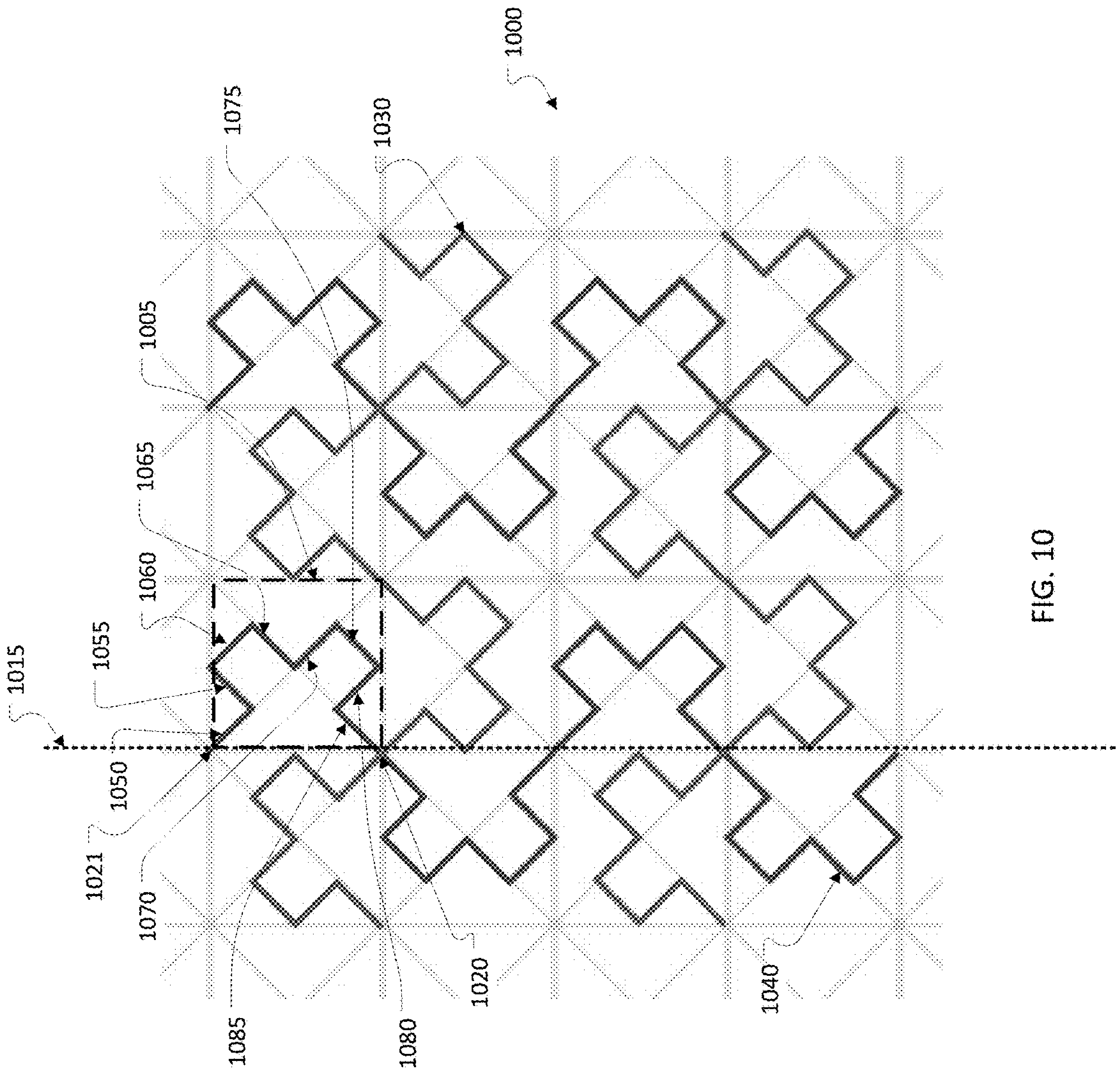
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FIG. 10

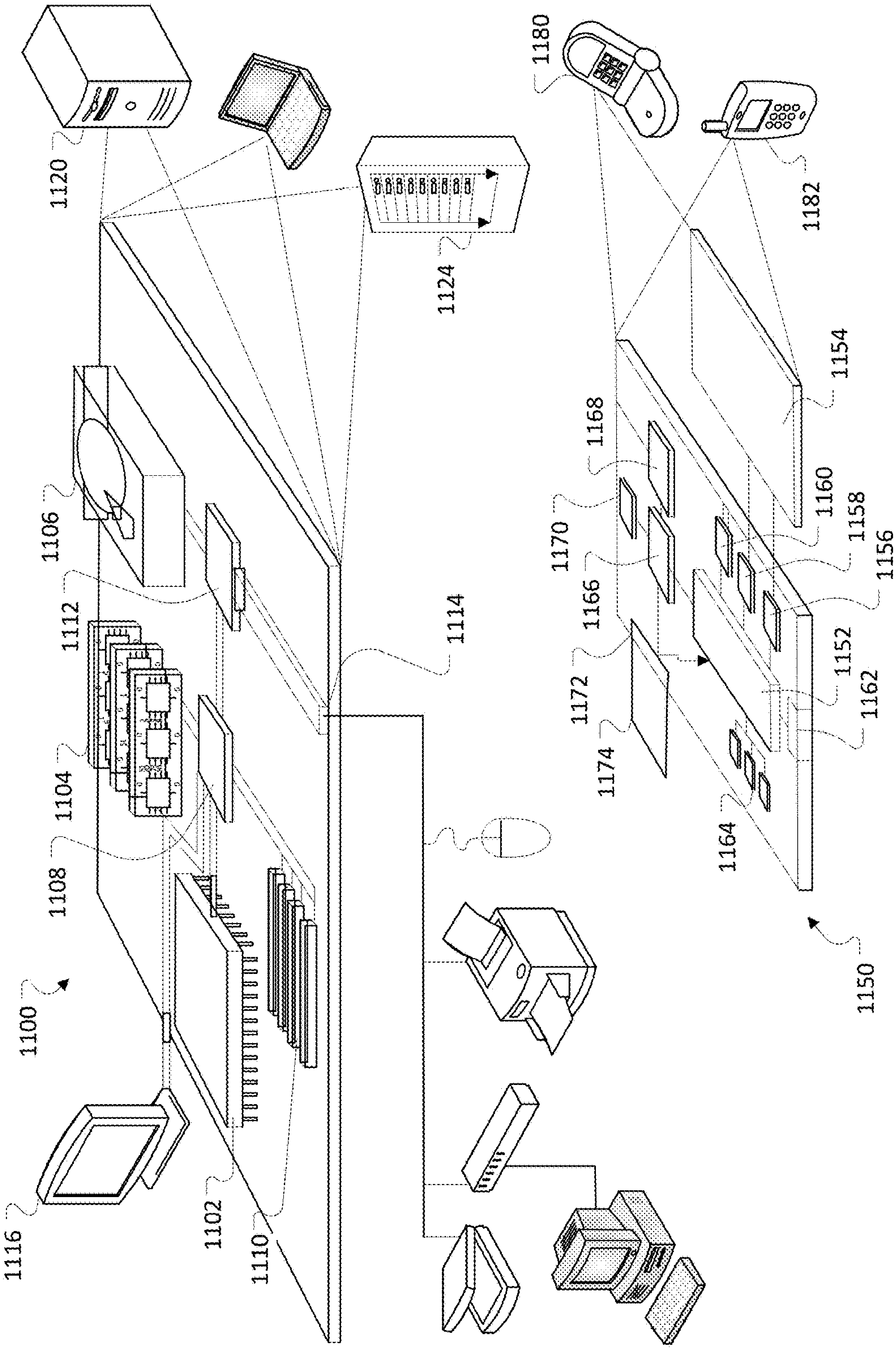
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FIG. 11

CAPACITIVE TOUCH SENSOR

TECHNICAL FIELD

The present disclosure relates to a projected capacitive touch sensor.

BACKGROUND

Touch-sensitive displays are widely employed for an expanding variety of applications ranging from mobile devices to fixed devices.

Projected Capacitive Technology (PCT) is becoming one of the most significant touch technologies for applications ranging from mobile devices to collaborative business and development. PCT refers to two main sensing methods called "self-capacitance" and "mutual capacitance" offering different performance characteristics and applications. Driven by the increasing number of users of touch-enabled mobile devices, consumer and professional expectations for touch applications have moved far beyond single-touch requirements into the realm of multi-touch and multi-user capabilities.

SUMMARY

To detect touches on a display screen, a touch sensor grid is overlaid on top of the display screen such that the sensor grid is between the user and the display screen. The traces may consist of patterns with straight lines and sharp corners or patterns with curved lines. Each trace for the sensor grids exhibits bilateral symmetry, rotational symmetry, or both. The traces different trace patterns each have benefits and drawbacks related to production time, production cost, visual interference, and accuracy.

An innovative aspect of the subject matter described in this specification may be implemented in a projected capacitive touch sensor that includes a sensor grid that includes a trace that (i) has a trace start point and a trace end point, (ii) is electrically conductive between the trace start point and the trace end point, (iii) is formed in one or more pairs of trace cells that each include a first trace cell and a second trace cell that is rotationally symmetrical to the first trace cell, where the trace start point and the trace end point define a trace axis, where a trace direction is defined from the trace start point to the trace end point, where a trace-perpendicular direction is defined as being perpendicular to the trace direction, where a segment of the trace that is formed in the first trace cell includes a first portion of the trace that starts at a first point on the trace axis and that is formed in the trace direction and in the trace-perpendicular direction; a second portion of the trace that starts at an end point of the first portion and that is formed in a direction opposite the trace direction and in the trace-perpendicular direction; a third portion of the trace that starts at an end point of the second portion and that is formed in the trace direction and in the trace-perpendicular direction; a fourth portion of the trace that starts at an end point of the third portion and that is formed in the trace direction and in a direction opposite the trace-perpendicular direction; a fifth portion of the trace that starts at an end point of the fourth portion and that is formed in the trace direction and the trace-perpendicular direction; a sixth portion of the trace that starts at an end point of the fifth portion and that is formed in the trace direction and the direction opposite trace-perpendicular direction; a seventh portion of the trace that starts at an end point of the sixth portion and that is formed in the direction opposite the trace direction and the direction opposite trace-perpendicular direction; and an eighth portion of the trace that starts at an end point of the seventh portion, that ends at a second point on the trace axis, and that is formed in the trace direction and the direction opposite trace-perpendicular direction.

These and other implementations can each optionally include one or more of the following features. A width of the trace is between one micrometer and twenty micrometers. The sensor further includes additional traces that each have trace axes that are approximately parallel to the trace axis of the trace. The sensor further includes additional traces that each (i) have trace axes that are approximately perpendicular to the trace axis of the trace and (ii) are radially symmetrical to the trace.

Another innovative aspect of the subject matter described in this specification may be implemented in a projected capacitive touch sensor that includes a sensor grid that includes a trace that (i) has a trace start point and a trace end point, (ii) is electrically conductive between the trace start point and the trace end point, (iii) is formed in one or more pairs of trace cells that each include a first trace cell and a second trace cell that is rotationally symmetrical to the first trace cell, where the trace start point and the trace end point define a trace axis, where a trace direction is defined from the trace start point to the trace end point, where a trace-perpendicular direction is defined as being perpendicular to the trace direction, where a segment of the trace that is formed in the first trace cell includes a first portion of the trace that starts at a first point on the trace axis and that is formed in the trace direction and in the trace-perpendicular direction; a second portion of the trace that starts at an end point of the first portion and that is formed in a direction opposite the trace direction and in the trace-perpendicular direction; a third portion of the trace that starts at an end point of the second portion and that is formed in the trace direction and in the trace-perpendicular direction; a fourth portion of the trace that starts at an end point of the third portion, that ends at a second point on the trace axis, and that is formed in the trace direction and in a direction opposite the trace-perpendicular direction.

These and other implementations can each optionally include one or more of the following features. A width of the trace is between one micrometer and twenty micrometers. The sensor further includes additional traces that each have trace axes that are approximately parallel to the trace axis of the trace. The sensor further includes additional traces that each (i) have trace axes that are approximately perpendicular to the trace axis of the trace and (ii) are radially symmetrical to the trace. A length of the fourth portion is at least twice a length of the first portion, the second portion, or the third portion.

Another innovative aspect of the subject matter described in this specification may be implemented in a projected capacitive touch sensor that includes a sensor grid that includes a trace that (i) has a trace start point and a trace end point, (ii) is electrically conductive between the trace start point and the trace end point, (iii) is formed in one or more pairs of trace cells that each include a first trace cell and a second trace cell that is rotationally symmetrical to the first trace cell, where the trace start point and the trace end point define a trace axis, where a trace direction is defined from the trace start point to the trace end point, where a trace-perpendicular direction is defined as being perpendicular to the trace direction, where a segment of the trace that is formed in the first trace cell includes a first portion of the trace that starts at a first point on the trace axis and that is formed in the trace direction and in the trace-perpendicular direction; a second portion of the trace that starts at an end point of the first portion and that is formed in the trace direction and in a direction that is opposite the trace-perpendicular direction; a third portion of the trace that starts at an end point of the second portion and that is formed in the trace direction and in the trace-perpendicular direction; a fourth portion of the trace that starts at an end point of the third portion, that ends at a second point on the trace axis, and that is formed in the trace direction and in the direction opposite the trace-perpendicular direction.

These and other implementations can each optionally include one or more of the following features. A width of the trace is between one micrometer and twenty micrometers. The sensor further includes additional traces that each have trace axes that are approximately parallel to the trace axis of the trace. The sensor further includes additional traces that each (i) have trace axes that are approximately perpendicular to the trace axis of the trace and (ii) are radially symmetrical to the trace.

Another innovative aspect of the subject matter described in this specification may be implemented in a projected capacitive touch sensor that includes a sensor grid that includes a trace that (i) has a trace start point and a trace end point, (ii) is electrically conductive between the trace start point and the trace end point, (iii) is formed in one or more pairs of trace cells that each include a first trace cell and a second trace cell that is rotationally symmetrical to the first trace cell, where the trace start point and the trace end point define a trace axis, where a trace direction is defined from the trace start point to the trace end point, where a trace-perpendicular direction is defined as being perpendicular to the trace direction, where a segment of the trace that is formed in the first trace cell includes a first curved portion of the trace that starts at a first point on the trace axis and that is concave in a direction opposite the trace direction; a second curved portion of the trace that starts at an end point of the first curved portion and that is convex in a direction opposite the trace direction and in the trace-perpendicular direction; a third curved portion of the trace that starts at an end point of the second curved portion and that is concave in the trace-perpendicular direction; a fourth curved portion of the trace that starts at an end point of the third curved portion and that is convex in the trace direction and in the trace-perpendicular direction; a fifth curved portion of the trace that starts at an end point of the fourth curved portion, that ends at a second point on the trace axis and that is concave in the trace direction.

These and other implementations can each optionally include one or more of the following features. A width of the trace is between one micrometer and twenty micrometers. The sensor further includes additional traces that each have trace axes that are approximately parallel to the trace axis of the trace. The sensor further includes additional traces that each (i) have trace axes that are approximately perpendicular to the trace axis of the trace and (ii) are radially symmetrical to the trace. The first curved portion, the second curved portion, the third curved portion, the fourth curved portion, and the fifth curved portion are arcs with a same radius. The first curved portion, the third curved portion, and the fifth curved portion are arcs with a first radius. The second curved portion and the fourth curved portion are arcs with a second radius that is greater than the first radius. The first curved portion, the third curved portion, and the fifth curved portion are arcs with a first radius. The second curved portion and the fourth curved portion are arcs with a second radius that is less than the first radius.

Other implementations of these aspects include corresponding systems, apparatus, and computer programs recorded on computer storage devices, each configured to generate these sensors.

The details of one or more implementations of the subject matter described in this specification are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages of the subject matter will become apparent from the description, the drawings, and the claims.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** illustrates how projected capacitive touch sensing works.

FIG. **2** illustrates components of a projected capacitive touch sensor.

FIG. **3**A illustrates a front view of a touch display device based on a projected capacitive touch sensor.

FIG. **3**B illustrates a top view of a touch display device based on a projected capacitive touch sensor.

FIG. **4**A illustrates layers of the sensor grid in a face-to-face stacking.

FIG. **4**B illustrates layers of the sensor grid in a bridged stacking.

FIG. **4**C illustrates layers of the sensor grid in a dual-side stacking.

FIGS. **5**A, **6**, **7**A, and **8**-**10** illustrate example sensor patterns.

FIGS. **5**B and **7**B illustrate example row patterns of example sensor patterns.

FIGS. **5**C and **7**C illustrate example column patterns of example sensor patterns.

FIG. **11** shows an example of a computing device and a mobile computing device.

DETAILED DESCRIPTION

The present disclosure relates to a projected capacitive touch sensor.

FIG. **1** illustrates the working principles of projected capacitive touch sensing technology. **101** is the sensor without an external conductive object in close proximity, while **102** is the sensor with an external conductive object in close proximity. PCT may be based on a grid (or matrix) made of electrically conductive material, having this material as columns and rows. The columns and rows may serve as electrodes. The detection method may be based on interference caused by an external conductive touch object (e.g., finger or conductive pointer that are grounded) on the electrostatic field generated between the rows and columns, more precisely at the interceptions between rows and columns—these interceptions may be designated as nodes. These nodes, electrically speaking, may behave like capacitors, with very low charge capacity, in the pico Farad (pF) range, and with charge variation in the femto Farad (fF) range when externally disturbed (for instance, when touching with the external object). In other words, PCT detects touch by measuring the capacitance at each addressable electrode. When a finger or a conductive object approaches an electrode, it disturbs the electromagnetic field and alters the capacitance. This change in capacitance can be measured by the electronics and then converted into X, Y locations that the system can use to detect touch.

FIG. **2** illustrates components of a projected capacitive touch sensor **200**. In an aspect, an alternate current signal is injected (AC signal) in one of the rows **203** and, on each column **201**, one may find the same signal with a fraction of the injected signal amplitude. The signal amplitude obtained on each column is the result of the original AC signal passing through the capacitor **202** created at the node (interception) between the selected row and the column. This sensor output amplitude may vary between columns due to physical and electrical differences that may exist for among columns (e.g., equivalent capacitors to each node have different charge capacities, thereof, different output signal values or amplitudes). For example, the electrical signal may be injected in the rows and collected at the columns, but the process works in reverse (one can inject the signals in the columns and collect it at the rows).

The signal amplitude at the columns output may be changed (e.g., it will be smaller or larger) when a conductive object, exterior to the grid, disturbs the electrostatic field created at the node between the row and column. This conductive object is, in this circuit context, the touching or "getting near" finger in the grid which will divert part of that electrostatic field to earth/ground. One may use this difference of signal amplitude (amplitude without touch minus amplitude with touch) to identify the presence of an exterior conductive object, thus, the existence of a touch event.

There are two main types of sensing methods, self-capacitance and mutual capacitance, where each has its own advantages and disadvantages. While for self-capacitance, each electrode is scanned individually, in mutual capacitance each electrode node or intersection is scanned for the determination of a touch event. Mutual capacitance may allow an unlimited number of unambiguous touches, may produce higher resolution than self-capacitance and may be less sensitive to electromagnetic interference (EMI) than self-capacitance. In self-capacitance, due to the scanning method, so-called ghost points may occur so that it may not be possible to unambiguously detect more than one touch event when using rows and columns. However, both types of sensing methods are based on a charge transfer between human-body or touch object and either single electrode or pair of electrodes.

Mutual capacitance is the intentional or unintentional capacitance between two "charge holding objects." Projected capacitance touch-screens intentionally create mutual capacitance between elements of columns and rows in the vicinity where each intersect the other. This allows the system electronics to measure each node (intersection) individually to detect multiple touches on the screen during one screen scan. When a touch object touches near an intersection or node, some of the mutual capacitance between the row and column is coupled to the touch object, which reduce the capacitance at the intersection as measured by the system electronics. This reduced capacitance crosses the "touch threshold" set by the electronics indicating a touch has occurred.

Touch sensors based on PCT may be scanned as mentioned above. The term "scanned" as used herein may mean that individual electrodes (e.g. rows or columns) intersections or nodes are measured, e.g. one-by-one in a cycle. Mutual-capacitance touch screens may use a scanning method that measures the capacitance at each row and column intersection. In this scanning method, the controller drives a single column (Y) and then scans every row (X) (or vice versa) that intersects with that column, measuring the capacitance value at each X-Y intersection. This process may be repeated for every column and then the entire cycle starts over. The scanning rate may be more than 20 Hz, for example, up to 200 Hz, 400 Hz, or 500 Hz. The sensor grid may have any number of columns and rows, for example, 64-700 columns and 36-400 rows, for example 168 columns and 96 rows.

FIG. **3**A illustrates a front view of the projected capacitive touch display device **300** and FIG. **3**B illustrates a top view of the projected capacitive touch display device **300**. The projected capacitive touch sensor may include a sensor grid **301** with diagonal **305**, a display layer **302**, a glass (or other transparent, non-conductive material, like acrylic) cover layer **303**, one or more controllers **304** and one or more flexible cables **306**. The controller, despite being shown at the back of the display, can be located anywhere as long as the flexible cables **306** coming from the sensor film can reach it. Not shown here is the host system (e.g., a regular PC) where the controller **304** and the display **302** are connected. The sensor grid **301** may be laminated to the glass **303** (or other transparent, non-conductive material, like acrylic). The diagonal **305** may exceed 32 inches, preferably may be 40 inches to 90 inches, more preferably may be up to 150 inches.

The layers forming the sensor grid **301**, after being stacked up, may create a grid of interceptions between the conductive material (e.g., copper, gold, silver, carbon nanotubes, graphene; generically any conductive material which may allow fine traces, e.g. below 10 μm in width) rows and columns, which are previously created in one or more row or column layers by deposition, printing, etching, electroplating or other method of making conductive structures in (e.g. flexible) substrates (e.g.). Additionally, conductive connecting traces (e.g. buses) are also created at the borders in order to allow the electrical connection of the rows/columns to the flexible cables which will, then, connect to the controller. The rows and their traces may not directly (e.g., conductively) touch/connect electrically to the columns and column traces, e.g., there must may be electrical isolation between rows and columns, being it by spatial separation (zones where rows and columns do not overlap), or being it by using a isolating (e.g., electrically non-conductive) layer (e.g. an optically clear adhesive (OCA)) in between. The isolation material may act as dielectric, e.g., at the interception/node zones.

As used in the present disclosure, the term "controller" and "host system" is intended to encompass any suitable processing device. For example, although FIGS. **3**A, **3**B illustrate a single backend controller **304**, touch display device **300** can be implemented using any number of controllers. Indeed, the controller **304** and the host system may be any computer or processing device such as, for example, a blade server, general-purpose personal computer (PC), Macintosh®, workstation, UNIX®-based workstation, or any other suitable device. In other words, the present disclosure contemplates computers other than general purpose computers, as well as computers without conventional operating systems. Further, the illustrated controller **304** and the host system may be adapted to execute any operating system, including Linux®, UNIX®, Windows®, Mac OS®, or any other suitable operating system. The controller and/or host system may be configured to execute any computer instructions or software that can be used to operate the touch display device **300** or that can provide functionality for one or more users of the touch display device **300**, wherein the users may activate the functionality through touching predetermined locations on the cover layer **303**, and wherein the touched location is associated with an icon displayed by the display layer **302**, and wherein the user-initiated touch event is sensed by the sensor grid **301** and the controller **304**. In this manner, the user may activate software or hardware functionality by perturbing the electrical field at a node of a row and a column of the sensor grid **301** by using a finger or a conductive object. For example, the perturbation of the electrical field triggers an action of software running on the controller **304** or host system.

FIG. **4**A illustrates layers of the sensor grid **301**, **400***a* in a face-to-face stacking according to an embodiment of the present disclosure. The sensor grid may comprise one or more layers, which may be at least one of: conductive row layer **403***a*, conductive column layer **401***a*, optically clear adhesives **402***a*, substrates, covers, or additional dielectric bridges. For example, the sensor grid **301**, **400***a* may include a conductive row layer **403***a*, a conductive column layer **401***a* and an optically clear adhesive (OCA) **402***a*. The rows **405***a* and columns **404***a* may be electrodes that are conductively connected via cables or wires **406***a* with the controller **304**. FIG. **4**A illustrates the sensor grid before and after lamination, and relative to the display layer **302**. The materials used for the bridges and the OCA may be optically clear or transparent, and/or flexible materials, for example, materials with maximum haze below about 1%, and/or, with minimum light transmission, for example, above about 99%, for example an acrylic adhesive. The properties for bridge material may be: transparent, non-conductive, flexible, and/or dielectric constant substantially equivalent to glass, acrylic, or polyester.

The sensor grid layers stacking may be dependable on how the conductive rows and columns are created. There are three layer stacking configurations normally used: separated rows and columns layers facing each other (face to face stacking, FIG. **4**A), rows and columns in the same layer (bridged stacking, FIG. **4**B), rows and columns on opposite side of the same layer (dual side, FIG. **4**C). The substrate layers (where the rows and columns will be created) and the cover layers may be polyethylene terephthalate (PET) films or other types of at least partially transparent (e.g. within or across the visible spectrum) and flexible materials. For example, polymethylpentene (PMP), polypropylene (PP), polycarbonate (PC), polyvinyl chloride (PVC), poly(methyl methacrylate) (PPMA), polystyrene (PS), styrene acrylonitrile (SAN), among others. Also, a flexible glass material can be used. In the next sub-sections, the aforementioned configurations are illustrated.

In this face-to-face stacking configuration **400***a*, the rows and the columns are created in separated layers, with the printed side facing each other. To isolate them electrically and, at the same time, act as dielectric, and to bond them when laminated, one may use a non-conductive layer of optically clear adhesive (OCA). The flexible cables may be bonded or soldered to the corresponding traces or buses (before or after the layer lamination, depending on the production process used).

FIG. **4**B illustrates layers of the sensor grid **301**, **400***b* in a bridged stacking according to an embodiment of the present disclosure. The sensor grid may comprise one or more layers, which may be at least one of: a layer **408***b* shared by conductive rows **405***b* and conductive columns **404***b*, optically clear adhesives **402***b*, substrates, covers **407***b*, or additional dielectric bridges. For example, the sensor grid **301**, **400***b* may include a layer **408***b* shared by conductive rows **405***b* and conductive columns **404***b* (e.g., rows and columns in the same layer **408***b*), and an optically clear adhesive (OCA) positioned between each row **405***b* and column **404***b* at the respective row-column-nodes. The rows **405***b* and columns **404***b* may be electrodes that are conductively connected via cables or wires **406***a* with the controller **304**. FIG. **4**B illustrates the sensor grid before and after lamination, and relative to the display layer **302**.

In this bridged stacking configuration **400***b*, the rows and the columns may be created in the same layer **408***b*, having a transparent non-conductive material (e.g. OCA) between them where their projections spatially overlap. These non-conductive material blocks are called dielectric bridges. They may isolate electrically the rows and columns and act as dielectric. Also, it is used a cover layer to close and protect the rows and columns traces and an OCA layer to bond them when laminated. The flexible cables **406***a* may be bonded or soldered to the corresponding buses (before or after the layer lamination, depending on the production process used).

FIG. **4**C illustrates layers of the sensor grid **301**, **400***c* in a dual-side stacking according to an embodiment of the present disclosure. The sensor grid may comprise one or more layers, which may be at least one of: a layer **408***c* shared by conductive rows **405***c* and conductive columns **404***c*, optically clear adhesives **402***c*, substrates, covers **407***c*, or additional dielectric bridges. For example, the sensor grid **301**, **400***c* may include a layer **408***c* shared by conductive rows **405***c* and conductive columns **404***c* (e.g., rows and columns on opposite side of the same layer **408***c*), and one or more optically clear adhesive (OCA) layers positioned between layer **408***c* and one or more cover layers **407***c*. The rows **405***c* and columns **404***c* may be electrodes that are conductively connected via cables or wires **406***c* with the controller **304**. FIG. **4**B illustrates the sensor grid before and after lamination, and relative to the display layer **302**.

In this dual-side stacking configuration **400***c*, the rows and the columns may be created in the same layer **408***c*, but on opposite sides, e.g., having the layer substrate **408***c*, the rows are created on the top side (e.g. top surface) and the columns on the bottom side (e.g., bottom surface), or vice-versa, of the shared layer **408***c*. The substrate layer may act as isolator and a dielectric. One may use a cover layer **407***c* on each side of the layer **408***c* to close and protect the rows and columns traces and the one or more OCA layers **402***c*, e.g., also on each side to bond them when laminated. The flexible cables **406***a* connect the rows and columns to the controller **304**, e.g. cables **406***a* may be bonded or soldered to the corresponding traces or buses (before or after the layer lamination, depending on the production process used).

As noted above, the sensor grid, or sensor foil, may be located on top of a screen, e.g., an LCD screen, and may interfere with a user's viewing of the screen, especially when the conductive material that makes up the traces of the sensor foil are not transparent, which is typically the case, because the traces are usually metal. With the sensor foil covering a portion of the screen, the sensor may cause a number of visual interference effect such as hazing, blurring, or a moiré effect. To reduce these effects, the traces of the sensor foil should cover as small a portion of the screen as possible without compromising sensitivity of the touch sensing capabilities of the sensor foil. Typically, the transparency range for sensor foils range between eighty-five percent to nearly one hundred percent.

The hazing and blurring effects may be caused by a number of factors such as trace width and trace pitch. With respect to trace width, the traces cover more area as the trace widths increase. With respect to trace pitch, which is the distance from the middle of a trace to the middle of an adjacent trace of an adjacent row or column, the traces cover less area as the trade pitch increases. Sensor foils with large trace widths and small trace pitches will likely cause hazing, blurring, or both when a user views a screen under the sensor foil.

The moiré effect may be tied to a relationship between the trace widths, pitches, patterns, and orientations and the pixel sizes and pitches of the underlying screen. For example, a pixel pitch that is near the trace pitch and a pixel grid that is nearly in line with a trace grid will cause a strong moiré effect with the effect increasing the closer in line the pixel grid and trace grid become. Also, as row traces and column traces approach a perpendicular orientation, the moiré effect becomes more pronounced, with it being strongest when the row traces are perpendicular to the column traces.

FIG. **5**A illustrates an example sensor pattern **500***a*. FIG. **5**B illustrates an example row pattern **500***b* of an example sensor. FIG. **5**C illustrates an example column pattern **500***c* of an example sensor. The sensor pattern **500***a* is a combination of the row pattern **500***b* and the column pattern **500***c*. The sensor pattern **500***a* may be repeated multiple times in a sensor grid, or sensor foil.

The sensor pattern **500***a* may be divided into cells such as cell **505***a* and cell groups such as cell group **510***a*. The sensor pattern **500***a* that is formed in cell **505***a* may be repeated around a trace axis **515***a* to generate a trace. For example, cell **505***c* is repeated around trace axis **515***c* to generate the traces of column pattern **500***c*. Cell **505***b* is repeated around trace axis **515***b* to generate the traces of row pattern **500***b*.

The sensor pattern **500***a* is constructed using five connected arcs on each cell. Replicating this arc pattern to fill all the sensor foil area generates an organized trace pattern. The pattern **500***a* includes a sequence of rows and columns where the rows are arranged in an independent row layer **500***b* and the columns are arranged in an independent column layer **500***c*, that when overlapped, form one integrated sensor layer **500***a* with touch sensitivity and conductive object detection. In some implementations, the overlap between the column layer **500***c* and row layer **500***b* occurs without the use of a non-conductive physical layer between the column layer **500***c* and row layer **500***b*.

The traces of sensor pattern **500***a* may be made of silver, copper, gold, or other conductive materials. The width of the traces may be between one micrometer and twenty micrometers. Because the sensor pattern **500***a* is not aligned with the pixel grid of the display screen, the sensor patter may exhibit a reduced moiré effect.

In addition to reducing visual interferences, production considerations are also a factor when designing sensor patterns. A sensor pattern should not be so complex as to increase production time or decrease yield to a point where manufacturing of the sensor pattern becomes impractical.

The cell **505***c* of one of the column traces of sensor pattern **500***c* may be divided into different portions. In particular cell **505***c* includes a first portion **550***c*, a second portion **555***c*, a third portion **560***c*, a fourth portion **565***c*, and a fifth portion **570***c*. Each of the portions may be arcs that are defined by a radius. In some implementations, all the radii for cell **505***c* are different, and in some implementations, the radii are the same. In some implementations, the radii of the first portion **550***c*, the third portion **560***c*, and the fifth portion **570***c* are a first distance, and the radii of the second portion **565***c* and the fourth portion **575***c* are a second, different distance. For example, the first distance may be five micrometers and the second distance may be ten micrometers. The first distance may be ten micrometers and the second distance may be five micrometers. The first distance and the second distance may be the same, for example, seven micrometers. In some implementations, the first portion **550***c*, the second portion **555***c*, the third portion **560***c*, the fourth portion **565***c*, and the fifth portion **570***c* may be curved lines other than arcs such as a parabolic curve, elliptical curve, logarithmic curve, exponential curve, or hyperbolic curve.

FIG. **6** illustrates an example sensor pattern **600**. The sensor pattern **600** is similar to sensor pattern **500***a* except that the arcs that form the sensor pattern **600** have larger radii. The sensor pattern **600** is a pattern that replicates the pattern in cell **605** around a trace axis **615**. Cell group **610** includes four cells.

The cell **605** includes five connected arcs that have lager radii than the connected arcs of sensor pattern **500***a*. Therefore the traces of sensor pattern **600** exhibit smoother characteristics than the traces of sensor pattern **500***a*. The length of the overall traces are shorter in sensor pattern **600** than in sensor pattern **500***a* and thus have a lower resistance.

Similar to the sensor pattern **500***a*, a row or column trace may be formed by replicating the cell **605** around the trace axis **615**. Cell **625** is a mirror image of cell **605** that is translated along the trace axis **615** the width of the cell **625**. In other words, cell **625** is reflectionally symmetrical to the cell **605**. Cell **605** and cell **625** may also be considered rotationally symmetrical about the point **620** using one hundred eighty degrees of rotation. These reflections and translations or rotations continue along the trace axis **615** to form a complete row or column trace.

The fill an entire sensor foil with the traces similar to the trace along trace axis **615**, the trace along trace axis **615** is replicated. Each new trace includes a trace axis that is parallel to the trace axis **615** to form a complete row group or column group. The complete row group or column group may be rotated ninety degrees to form the other group, whether it be the row or column group. In some implementations, the width of the traces in sensor pattern **600** are between one micrometer and twenty micrometers.

The cell **605** of one of the column traces of sensor pattern **600** may be divided into different portions. In particular, cell **605** includes a first portion **650**, a second portion **655**, a third portion **660**, a fourth portion **665**, and a fifth portion **670**. Each of the portions may be arcs that are defined by a radius. In some implementations, all the radii for cell **605** are different, and in some implementations, the radii are the same. In some implementations, the radii of the first portion **650**, the third portion **660**, and the fifth portion **670** are a first distance, and the radii of the second portion **665** and the fourth portion **675** are a second, different distance. For example, the first distance may be ten micrometers and the second distance may be seven micrometers. The first distance may be seven micrometers and the second distance may be ten micrometers. The first distance and the second distance may be the same, for example, eight micrometers. In some implementations, the first portion **650**, the second portion **655**, the third portion **660**, the fourth portion **665**, and the fifth portion **670** may be curved lines other than arcs such as a parabolic curve, elliptical curve, logarithmic curve, exponential curve, or hyperbolic curve.

FIG. **7**A illustrates an example sensor pattern **700***a*. FIG. **7**B illustrates an example row pattern **700***b* of an example sensor. FIG. **7**C illustrates an example column pattern **700***c* of an example sensor. The sensor pattern **700***a* is a combination of the row pattern **700***b* and the column pattern **700***c*. The sensor pattern **700***a* may be repeated multiple times in a sensor grid, or sensor foil.

Unlike sensor patterns **500***a* and **600**, sensor pattern **700***a* does not include both rotationally symmetric rows and columns. The row traces of row pattern **700***b* are wavy, and the column traces of column pattern **700***c* are more angular. The wavy traces of sensor pattern **700***a* avoid moiré interferences when placed over the pixel grid of a display. Additionally, the sensor pattern **700***a* has a lower production time than sensor patterns **500***a* and **600**. The sensor pattern **700***a* also has a higher transparency than sensor patterns **500***a* and **600**.

For column pattern **700***c*, the cell **710***c* is replicated to produce the column pattern **700***c*. The trace axis **715***c* divides the cell **710***c* and provides a rotation axis about which to rotate the cell **710***c*. The rotated cell **710***c* is translated vertically and horizontally to form the column pattern **700***c* along trace axis **715***c* and parallel to trace axis **715***c*. Horizontally translating the portion of sensor pattern **700***c* without rotating around trace axis **715***c* yields incorrectly formed columns. Row pattern **700***b* exhibits rotational symmetry of cell **710***a* about trace axis **715***b*. The rotated cells **710***a* are translated horizontally. Once a row is formed about the trace axis **715***b*, the complete row is then translated vertically. The row pattern **700***b* and column pattern **700***c* combine to form the sensor pattern **700***a* with trace axis **715***b* perpendicular to trace axis **715***c*. In some implementations, the cell **710***a* is similar in size to cell groups **510***a* and **610**. In some implementations, the cell **710***a* is similar in size to cell **505***a* and **605**. In some implementations, the width of the traces of sensor pattern **700***a* are between one micrometer and twenty micrometers.

The cell **710***b* of one of the row traces of sensor pattern **700***b* includes a portion **750***b* of the row trace. The portion **750***b* may form an arc with a radius. In some implementations, the portion **750***b* is a curved line other than an arc such as a parabolic curve, elliptical curve, logarithmic curve, exponential curve, or hyperbolic curve.

The cell **710***c* of one of the column traces of sensor pattern **700***c* may be divided into different portions. In particular, cell **710***c* includes a first portion **750***c*, a second portion **755***c*, and a third portion **760***c*. Each of the portions may be arcs that are defined by a radius. In some implementations, all the radii for cell **710***c* are different, and in some implementations, the radii are the same. The radii for the cell **710***c* may be the same or different than the radius for cell **710***b*. In some implementations, the radii of the first portion **750***c* and the third portion **760***c* are a first distance, and the radius of the second portion **665** is a second, different distance. For example, the first distance may be twenty micrometers and the second distance may be twenty-five micrometers. The first distance may be fifteen micrometers and the second distance may be thirty micrometers. The first distance and the second distance may be the same, for example, forty micrometers. In some implementations, the first portion **750***c*, the second portion **755***c*, and the third portion **760***c* may be curved lines other than arcs such as a parabolic curve, elliptical curve, logarithmic curve, exponential curve, or hyperbolic curve. In some implementations, the second portion **755***c* is concave with respect to the trace axis **715***c*, and in some implementations, the second portion **755***c* is convex with respect to the trace axis **715***c*. In some implementations the first portion **750***c* and the third portion **760***c* are a same length and shorter than the second portion **755***c*, when the lengths are defined from endpoint to endpoint for each of the portions.

In some implementations, the curvature of the row traces may be in the same direction or the opposite direction compared to the curvature of the first portion and third portion of the column traces. For example, sensor pattern **700***a* includes column traces that have first portions and third portions with a same curvature as the portion of the row trace.

FIGS. **8-10** illustrate example sensor patterns **800**, **900**, and **1000**. Each of the sensor patterns **800**, **900**, and **1000** include traces formed with straight lines and right angles. This is in contrast to the sensor patterns **500***a*, **600**, and **700***a* that were formed with curved lines. Similar to sensor patterns **500***a* and **600**, sensor patterns **800**, **900**, and **1000** exhibit rotational symmetry about a point on a trace axis.

Sensor pattern **800** includes example column trace **840** that has a trace axis **815** and cell **805**. The cell **805** includes four trace portions. Three of the trace portions are about the same length and a fourth trace portion is about three times the length of the other trace portions. Each of the trace portions makes electrical contact with another trace portion at about a ninety degree angle.

To form column trace **840**, cell **805** is rotated one hundred eighty degrees about point **820**. Rotation about points on the trace axis **815** continues in order to complete forming of the column trace **840**. The sensor pattern **840** includes additional column traces that include trace axes that are parallel to trace axis **815**. The row traces, including row trace **830**, are formed by rotating the column traces ninety degrees. The row traces and column traces overlap at rotation points that are located on the trace axes. For example, row trace **830** and column trace **840** overlap, but do not make direct electrical contact, at point **820**.

In some implementations, the row and column traces of sensor pattern **800** are between one micrometer and twenty micrometers. The trace widths, angles, and lengths may vary within a particular tolerance. For example, the tolerance of the angles where the portions of column trace **840** meet may be less than one percent, less than two percent, or another percent. One angle between two portions may be eighty-nine degrees, and another angle may be ninety-one degrees. One trace portion may be 1.01 times the length of another trace portion.

The cell **805** of column trace **840** of sensor pattern **800** may be divided into different portions. In particular, cell **805** includes a first portion **850**, a second portion **855**, a third portion **860**, and a fourth portion **865**. The fourth portion **865** includes an endpoint at point **820**, and the first portion **850** includes an endpoint at point **821**. Each of the portions may be straight and have a particular length. In some implementations, all the lengths of the portions for cell **805** are different, and in some implementations, all the lengths are the same. In some implementations, the lengths of the first portion **850**, the second portion **855**, and the third portion **860** are first distance, and the length of the fourth portion **865** is a second, different distance. For example, the first distance may be three micrometers and the second distance may be ten micrometers. The first distance may be seven micrometers and the second distance may be fourteen micrometers. The first distance and the second distance may be the same, for example, five micrometers. In some implementations, the first portion **850**, the second portion **855**, the third portion **860**, and the fourth portion **865** meet at ninety degree angles. In some implementations, the first portion **850**, the second portion **855**, the third portion **860**, and the fourth portion **865** meet at angles between eighty degrees and one hundred degrees. In some implementations, the first portion **850**, the second portion **855**, the third portion **860**, and the fourth portion **865** may be curved lines such as arcs, parabolic curves, elliptical curves, logarithmic curves, exponential curves, or hyperbolic curves.

Sensor pattern **900** includes example column trace **940** that has a trace axis **915** and cell **905**. The cell **915** includes four trace portions. Each of the trace portions are about the same length. Each of the trace portions within the cell **905** makes electrical contact with another trace portion at about a twenty-eight degree angle.

To form column trace **940**, cell **905** is rotated one hundred eighty degrees about point **920**. Rotation about points on the trace axis **915** continues in order to complete forming of the column trace **940**. The sensor pattern **940** includes additional column traces that include trace axes that are parallel to trace axis **915**. The row traces, including row trace **930**, are formed by rotating the column traces ninety degrees. The row traces and column traces overlap at rotation points that are located on the trace axes. For example, row trace **930** and column trace **940** overlap, but do not make direct electrical contact, at point **920**.

In some implementations, the row and column traces of sensor pattern **900** are between one micrometer and twenty micrometers. The trace widths, angles, and lengths may vary within a particular tolerance. For example, the tolerance of the angles where the portions of column trace **840** meet may be less than one percent, less than two percent, or another percent. One angle between two portions may be twenty-seven degrees, and another angle may be twenty-nine degrees. One trace portion may be 1.02 times the length of another trace portion.

The cell **905** of column trace **940** of sensor pattern **900** may be divided into different portions. In particular, cell **905** includes a first portion **950**, a second portion **955**, a third portion **960**, and a fourth portion **965**. The fourth portion **965** includes an endpoint at point **920**, and the first portion **950** includes an endpoint at point **921**. Each of the portions may be straight and have a particular length. In some implementations, all the lengths of the portions for cell **905** are different, and in some implementations, all the lengths are the same. In some implementations, the lengths of the first portion **950** and the fourth portion **965** are first distance, and the lengths of the second portion **955** and the third portion **960** are a second, different distance. For example, the first distance may be three micrometers and the second distance may be ten micrometers. The first distance may be eight micrometers and the second distance may be four micrometers. The first distance and the second distance may be the same, for example, five micrometers. In some implementations, the first portion **850**, the second portion **855**, the third portion **860**, and the fourth portion **865** meet at twenty-nine degree angles. In some implementations, the first portion **850**, the second portion **855**, the third portion **860**, and the fourth portion **865** meet at angles between twenty degrees and forty degrees. In some implementations, the first portion **850**, the second portion **855**, the third portion **860**, and the fourth portion **865** may be curved lines such as arcs, parabolic curves, elliptical curves, logarithmic curves, exponential curves, or hyperbolic curves.

Sensor pattern **1000** includes example column trace **1040** that has a trace axis **1015** and cell **1005**. The cell **1015** includes eight trace portions. Each of the trace portions are about the same length. Each of the trace portions within cell **1005** makes electrical contract with another trace portion at about a ninety degree angle.

To form column trace **1040**, cell **1005** is rotated one hundred eighty degrees about point **1020**. Rotation about points on the trace axis **1015** continues in order to complete forming of the column trace **1040**. The sensor pattern **1040** includes additional column traces that include trace axes that are parallel to trace axis **1015**. The row traces, including row trace **1030**, are formed by rotating the column traces ninety degrees. The row traces and column traces overlap at rotation points that are located on the trace axes. For example, row trace **1030** and column trace **1040** overlap, but do not make direct electrical contact, at point **1020**.

In some implementations, the row and column traces of sensor pattern **1000** are between one micrometer and twenty micrometers. The trace widths, angles, and lengths may vary within a particular tolerance. For example, the tolerance of the angles where the portions of column trace **1040** meet may be less than one percent, less than two percent, or another percent. One angle between two portions may be eighty-eight degrees, and another angle may be ninety-two degrees. One trace portion may be 1.02 times the length of another trace portion. Each of the tolerance examples described may apply to any of the trace patterns in any combination.

The cell **1005** of column trace **1040** of sensor pattern **1000** may be divided into different portions. In particular, cell **1005** includes a first portion **1050**, a second portion **1055**, a third portion **1060**, a fourth portion **1065**, a fifth portion **1070**, a sixth portion **1075**, a seventh portion **1080**, and an eighth portion **1085**. The eighth portion **1085** includes an endpoint at point **1020**, and the first portion **1050** includes an endpoint at point **1021**. Each of the portions may be straight and have a particular length. In some implementations, all the lengths of the portions for cell **1005** are different, and in some implementations, all the lengths are the same.

In some implementations, the lengths of the first portion **1050**, the second portion **1055**, fourth portions **1065**, fifth portions **1070**, seventh portions **1080**, and eighth portions **1085** are first distance, and the lengths of the third portion **1060** and the sixth **1075** are a second, different distance. For example, the first distance may be three micrometers and the second distance may be ten micrometers. The first distance may be eight micrometers and the second distance may be five micrometers. The first distance and the second distance may be the same, for example, six micrometers. In some implementations, the first portion **1050**, the second portion **1055**, the third portion **1060**, the fourth portion **1065**, the fifth portion **1070**, the sixth portion **1075**, the seventh portion **1080**, and the eighth portion **1085** meet at ninety degree angles. In some implementations, the first portion **1050**, the second portion **1055**, the third portion **1060**, the fourth portion **1065**, the fifth portion **1070**, the sixth portion **1075**, the seventh portion **1080**, and the eighth portion **1085** meet at angles between eighty degrees and one hundred degrees. In some implementations, the first portion **1050**, the second portion **1055**, the third portion **1060**, the fourth portion **1065**, the fifth portion **1070**, the sixth portion **1075**, the seventh portion **1080**, and the eighth portion **1085** may be curved lines such as arcs, parabolic curves, elliptical curves, logarithmic curves, exponential curves, or hyperbolic curves.

In some implementations, the column traces may be rotated at angles other than ninety degrees to form the row traces. For example, the column traces may be rotated at angles between thirty degrees and sixty degrees, between forty-five degrees and seventy-five degrees, or between sixty degrees and ninety degrees. In some implementations, the cells may be rotated at angles other than one hundred eighty degrees about points on the trace axis. For example, cell **805** may be rotated between one hundred twenty degrees and two hundred forty degrees. When cells are rotated at angles other than one hundred eighty degrees the subsequent rotation of the cell should be adjusted so that the trace continues along the trace axis. For example, cell **1005** may be rotated about point **1020** one hundred seventy degrees. To continue forming column trace **1040**, the subsequent cell is rotated one hundred ninety degrees. Adjusting the rotation angles reduces the moiré effect.

In some implementations, different sensor patterns are combined to create one sensor grid. For example, sensor pattern **800** may form the center of a sensor grid and sensor pattern **900** may form the edges of the sensor grid. In some implementations, columns from one sensor pattern are combined with rows from another sensor pattern. For example, the column pattern **500***c* may form the columns of the sensor grid and row pattern **700***b* may form the rows of the sensor grid. Sensor patterns with mixed rows and columns may be combined with other sensor patterns that may or may not have mixed rows and columns. For example, the sensor pattern with column pattern **500***c* and row pattern **700***b* may form the center of the sensor grid and sensor pattern **1000** may form the edges. Because sensor grids typically exhibit lower sensitivity around the edges, designers may select edge sensor patterns that have higher sensitivity performance even if the visual interference is degraded. Designers may select sensor patterns with less visual interference for the middle of a sensor grid even if the selected sensor patterns exhibit lower sensitivity.

The following tables illustrate various performance metrics for the various sensor patterns. Table 1 shows the production time for each of the presented sensor patterns.

TABLE 1

Sensor production times for each sensor pattern

	Sensor Production Time (hours)					
	FIG. 10	FIG. 8	FIG. 6	FIG. 9	FIG. 5A	FIG. 7A
64 rows × 64 columns	5.13	2.18	1.45	2.6	1.49	0.47
48 rows × 84 columns	4.1	2.11	1.46	2.59	1.57	0.43
96 rows × 168 columns	14.3	4.09	5.04	9.5	5.41	2.24

Table 2 shows the results of empirical tests for each of the presented sensor patterns. Production time refers to the time required to produce a sensor grid using a particular sensor pattern. Transparency refers to the ability of the user to view the display under the sensor grid. The transparency of all the sensor patterns is greater than ninety-five percent. Visual interference refers to interference such as moiré interference, hazing, and blurring. Trace pitch variation refers to the tolerance level for each trace pitch, or the distance between neighboring rows or neighboring columns. Trace length refers to the total length of a particular trace instead of just the length of the particular trace's trace axis. Typically longer traces are more expensive to produce because of the additional material for each trace. Sensor pattern **1000** is well performing, but has the longest production time and trace length. Sensor pattern **600** has an acceptable production time and acceptable performance. Sensor pattern **700***a* has a low production time and low trace length, but high visual interference.

TABLE 2

Empirical test results

	Production time	Transparency	Visual interference	Trace pitch variation	Trace length	Conclusions
FIG. 10	Very high	High	Low	Low	High	Well performing
FIG. 8	High	High	Acceptable	Medium	Medium	
FIG. 6	Acceptable	High	Low	Medium	Medium	Acceptable trade-offs
FIG. 9	High	Acceptable	High	Low	High	
FIG. 5A	Acceptable	High	Low	Low	High	
FIG. 7A	Low	Very High	High	Low	Low	Lower cost

FIG. **11** shows an example of a computing device **1100** and a mobile computing device **1150** that can be used to implement the techniques and methods described here. The computing device **1100** is intended to represent various forms of digital computers, such as laptops, desktops, workstations, personal digital assistants, servers, blade servers, mainframes, and other appropriate computers. The mobile computing device **1150** is intended to represent various forms of mobile devices, such as personal digital assistants, cellular telephones, smart-phones, and other similar computing devices. The components shown here, their connections and relationships, and their functions, are meant to be examples only, and are not meant to be limiting.

The computing device **1100** includes a processor **1102**, a memory **1104**, a storage device **1106**, a high-speed interface **1108** connecting to the memory **1104** and multiple high-speed expansion ports **1110**, and a low-speed interface **1112** connecting to a low-speed expansion port **1114** and the storage device **1106**. Each of the processor **1102**, the memory **1104**, the storage device **1106**, the high-speed interface **1108**, the high-speed expansion ports **1110**, and the low-speed interface **1112**, are interconnected using various busses, and may be mounted on a common motherboard or in other manners as appropriate. The processor **1102** can process instructions for execution within the computing device **1100**, including instructions stored in the memory **1104** or on the storage device **1106** to display graphical information for a GUI on an external input/output device, such as a display **1116** coupled to the high-speed interface **1108**. In other implementations, multiple processors and/or multiple buses may be used, as appropriate, along with multiple memories and types of memory. Also, multiple computing devices may be connected, with each device providing portions of the necessary operations (e.g., as a server bank, a group of blade servers, or a multi-processor system).

The memory **1104** stores information within the computing device **1100**. In some implementations, the memory **1104** is a volatile memory unit or units. In some implementations, the memory **1104** is a non-volatile memory unit or units. The memory **1104** may also be another form of computer-readable medium, such as a magnetic or optical disk.

The storage device **1106** is capable of providing mass storage for the computing device **1100**. In some implementations, the storage device **1106** may be or contain a computer-readable medium, such as a floppy disk device, a hard disk device, an optical disk device, or a tape device, a flash memory or other similar solid state memory device, or an array of devices, including devices in a storage area network or other configurations. Instructions can be stored in an information carrier. The instructions, when executed by one or more processing devices (for example, processor **1102**), perform one or more methods, such as those described above. The instructions can also be stored by one or more storage devices such as computer- or machine-readable mediums (for example, the memory **1104**, the storage device **1106**, or memory on the processor **1102**).

The high-speed interface **1108** manages bandwidth-intensive operations for the computing device **1100**, while the low-speed interface **1112** manages lower bandwidth-intensive operations. Such allocation of functions is an example only. In some implementations, the high-speed interface **1108** is coupled to the memory **1104**, the display **1116** (e.g., through a graphics processor or accelerator), and to the high-speed expansion ports **1110**, which may accept various expansion cards (not shown). In the implementation, the low-speed interface **1112** is coupled to the storage device **1106** and the low-speed expansion port **1114**. The low-speed expansion port **1114**, which may include various communication ports (e.g., USB, Bluetooth, Ethernet, wireless Ethernet) may be coupled to one or more input/output devices, such as a keyboard, a pointing device, a scanner, or a networking device such as a switch or router, e.g., through a network adapter.

The computing device **1100** may be implemented in a number of different forms, as shown in the figure. For example, it may be implemented as a standard server **1120**, or multiple times in a group of such servers. In addition, it may be implemented in a personal computer such as a laptop computer **1122**. It may also be implemented as part of a rack server system **1124**. Alternatively, components from the computing device **1100** may be combined with other components in a mobile device (not shown), such as a mobile computing device **1150**. Each of such devices may contain one or more of the computing device **1100** and the mobile computing device **1150**, and an entire system may be made up of multiple computing devices communicating with each other.

The mobile computing device **1150** includes a processor **1152**, a memory **1164**, an input/output device such as a display **1154**, a communication interface **1166**, and a transceiver **1168**, among other components. The mobile computing device **1150** may also be provided with a storage device, such as a micro-drive or other device, to provide additional storage. Each of the processor **1152**, the memory **1164**, the display **1154**, the communication interface **1166**, and the transceiver **1168**, are interconnected using various buses, and several of the components may be mounted on a common motherboard or in other manners as appropriate.

The processor **1152** can execute instructions within the mobile computing device **1150**, including instructions stored in the memory **1164**. The processor **1152** may be implemented as a chipset of chips that include separate and multiple analog and digital processors. The processor **1152** may provide, for example, for coordination of the other components of the mobile computing device **1150**, such as control of user interfaces, applications run by the mobile computing device **1150**, and wireless communication by the mobile computing device **1150**.

The processor **1152** may communicate with a user through a control interface **1158** and a display interface **1156** coupled to the display **1154**. The display **1154** may be, for example, a TFT (Thin-Film-Transistor Liquid Crystal Display) display or an OLED (Organic Light Emitting Diode) display, or other appropriate display technology. The display interface **1156** may comprise appropriate circuitry for driving the display **1154** to present graphical and other information to a user. The control interface **1158** may receive commands from a user and convert them for submission to the processor **1152**. In addition, an external interface **1162** may provide communication with the processor **1152**, so as to enable near area communication of the mobile computing device **1150** with other devices. The external interface **1162** may provide, for example, for wired communication in some implementations, or for wireless communication in other implementations, and multiple interfaces may also be used.

The memory **1164** stores information within the mobile computing device **1150**. The memory **1164** can be implemented as one or more of a computer-readable medium or media, a volatile memory unit or units, or a non-volatile memory unit or units. An expansion memory **1174** may also be provided and connected to the mobile computing device **1150** through an expansion interface **1172**, which may include, for example, a SIMM (Single In Line Memory Module) card interface. The expansion memory **1174** may provide extra storage space for the mobile computing device **1150**, or may also store applications or other information for the mobile computing device **1150**. Specifically, the expansion memory **1174** may include instructions to carry out or supplement the processes described above, and may include secure information also. Thus, for example, the expansion memory **1174** may be provide as a security module for the mobile computing device **1150**, and may be programmed with instructions that permit secure use of the mobile computing device **1150**. In addition, secure applications may be provided via the SIMM cards, along with additional information, such as placing identifying information on the SIMM card in a non-hackable manner.

The memory may include, for example, flash memory and/or NVRAM memory (non-volatile random access memory), as discussed below. In some implementations, instructions are stored in an information carrier that, when executed by one or more processing devices (for example, processor **1152**), perform one or more methods, such as those described above. The instructions can also be stored by one or more storage devices, such as one or more computer- or machine-readable mediums (for example, the memory **1164**, the expansion memory **1174**, or memory on the processor **1152**). In some implementations, the instructions can be received in a propagated signal, for example, over the transceiver **1168** or the external interface **1162**.

The mobile computing device **1150** may communicate wirelessly through the communication interface **1166**, which may include digital signal processing circuitry where necessary. The communication interface **1166** may provide for communications under various modes or protocols, such as GSM voice calls (Global System for Mobile communications), SMS (Short Message Service), EMS (Enhanced Messaging Service), or MMS messaging (Multimedia Messaging Service), CDMA (code division multiple access), TDMA (time division multiple access), PDC (Personal Digital Cellular), WCDMA (Wideband Code Division Multiple Access), CDMA2000, or GPRS (General Packet Radio Service), among others. Such communication may occur, for example, through the transceiver **1168** using a radio-frequency. In addition, short-range communication may occur, such as using a Bluetooth, WiFi, or other such transceiver (not shown). In addition, a GPS (Global Positioning System) receiver module **1170** may provide additional navigationand location-related wireless data to the mobile computing device **1150**, which may be used as appropriate by applications running on the mobile computing device **1150**.

The mobile computing device **1150** may also communicate audibly using an audio codec **1160**, which may receive spoken information from a user and convert it to usable digital information. The audio codec **1160** may likewise generate audible sound for a user, such as through a speaker, e.g., in a handset of the mobile computing device **1150**. Such sound may include sound from voice telephone calls, may include recorded sound (e.g., voice messages, music files, etc.) and may also include sound generated by applications operating on the mobile computing device **1150**.

The mobile computing device **1150** may be implemented in a number of different forms, as shown in the figure. For example, it may be implemented as a cellular telephone **1180**. It may also be implemented as part of a smart-phone **1182**, personal digital assistant, or other similar mobile device.

Various implementations of the systems and techniques described here can be realized in digital electronic circuitry, integrated circuitry, specially designed ASICs (application specific integrated circuits), computer hardware, firmware, software, and/or combinations thereof. These various implementations can include implementation in one or more computer programs that are executable and/or interpretable on a programmable system including at least one programmable processor, which may be special or general purpose, coupled to receive data and instructions from, and to transmit data and instructions to, a storage system, at least one input device, and at least one output device.

These computer programs (also known as programs, software, software applications or code) include machine instructions for a programmable processor, and can be implemented in a high-level procedural and/or object-oriented programming language, and/or in assembly/machine language. As used herein, the terms machine-readable medium and computer-readable medium refer to any computer program product, apparatus and/or device (e.g., magnetic discs, optical disks, memory, Programmable Logic Devices (PLDs)) used to provide machine instructions and/or data to a programmable processor, including a machine-readable medium that receives machine instructions as a machine-readable signal. The term machine-readable signal refers to any signal used to provide machine instructions and/or data to a programmable processor.

To provide for interaction with a user, the systems and techniques described here can be implemented on a computer having a display device (e.g., a CRT (cathode ray tube) or LCD (liquid crystal display) monitor) for displaying information to the user and a keyboard and a pointing device (e.g., a mouse or a trackball) by which the user can provide input to the computer. Other kinds of devices can be used to provide for interaction with a user as well; for example, feedback provided to the user can be any form of sensory feedback (e.g., visual feedback, auditory feedback, or tactile feedback); and input from the user can be received in any form, including acoustic, speech, or tactile input.

The systems and techniques described here can be implemented in a computing system that includes a back end component (e.g., as a data server), or that includes a middleware component (e.g., an application server), or that includes a front end component (e.g., a client computer having a graphical user interface or a Web browser through which a user can interact with an implementation of the systems and techniques described here), or any combination of such back end, middleware, or front end components. The components of the system can be interconnected by any form or medium of digital data communication (e.g., a communication network). Examples of communication networks include a local area network (LAN), a wide area network (WAN), and the Internet.

The computing system can include clients and servers. A client and server are generally remote from each other and typically interact through a communication network. The relationship of client and server arises by virtue of computer programs running on the respective computers and having a client-server relationship to each other.

Although a few implementations have been described in detail above, other modifications are possible. For example, while a client application is described as accessing the delegate(s), in other implementations the delegate(s) may be employed by other applications implemented by one or more processors, such as an application executing on one or more servers. In addition, the logic flows depicted in the figures do not require the particular order shown, or sequential order, to achieve desirable results. In addition, other actions may be provided, or actions may be eliminated, from the described flows, and other components may be added to, or removed from, the described systems. Accordingly, other implementations are within the scope of the following claims.

What is claimed is:

1. A projected capacitive touch sensor, comprising:

a sensor grid (a) that includes a trace that (i) has a trace start point and a trace end point, (ii) is electrically conductive between the trace start point and the trace end point, and (iii) is formed in one or more pairs of trace cells that each include a first trace cell and a second trace cell that is rotationally symmetrical to the first trace cell and (b) that includes additional traces that each (i) have trace axes that are approximately perpendicular to a trace axis of the trace and (ii) are radially symmetrical to the trace,

wherein the trace start point and the trace end point define the trace axis,

wherein a trace direction is defined from the trace start point to the trace end point,

wherein a trace-perpendicular direction is defined as being perpendicular to the trace direction,

wherein a segment of the trace that is formed in the first trace cell comprises:

a first portion of the trace that starts at a first point on the trace axis and that is formed in the trace direction and in the trace-perpendicular direction;

a second portion of the trace that starts at an end point of the first portion and that is formed in a direction opposite the trace direction and in the trace-perpendicular direction;

a third portion of the trace that starts at an end point of the second portion and that is formed in the trace direction and in the trace-perpendicular direction;

a fourth portion of the trace that starts at an end point of the third portion and that is formed in the trace direction and in a direction opposite the trace-perpendicular direction;

a fifth portion of the trace that starts at an end point of the fourth portion and that is formed in the trace direction and the trace-perpendicular direction;

a sixth portion of the trace that starts at an end point of the fifth portion and that is formed in the trace direction and the direction opposite trace-perpendicular direction;

a seventh portion of the trace that starts at an end point of the sixth portion and that is formed in the direction opposite the trace direction and the direction opposite trace-perpendicular direction; and

an eighth portion of the trace that starts at an end point of the seventh portion, that ends at a second point on the trace axis, and that is formed in the trace direction and the direction opposite trace-perpendicular direction.

2. The sensor of claim **1**, wherein a width of the trace is between one micrometer and twenty micrometers.

3. The sensor of claim **1**, wherein the sensor grid includes:

additional traces that each have trace axes that are approximately parallel to the trace axis of the trace.

4. A projected capacitive touch sensor, comprising:

a sensor grid (a) that includes a trace that (i) has a trace start point and a trace end point, (ii) is electrically conductive between the trace start point and the trace end point, and (iii) is formed in one or more pairs of trace cells that each include a first trace cell and a second trace cell that is rotationally symmetrical to the first trace cell and (b) that includes additional traces that each (i) have trace axes that are approximately perpendicular to a trace axis of the trace and (ii) are radially symmetrical to the trace,

wherein the trace start point and the trace end point define the trace axis,

wherein a trace direction is defined from the trace start point to the trace end point,

wherein a trace-perpendicular direction is defined as being perpendicular to the trace direction,

wherein a segment of the trace that is formed in the first trace cell comprises:

a first portion of the trace that starts at a first point on the trace axis and that is formed in the trace direction and in the trace-perpendicular direction;

a second portion of the trace that starts at an end point of the first portion and that is formed in a direction opposite the trace direction and in the trace-perpendicular direction;

a third portion of the trace that starts at an end point of the second portion and that is formed in the trace direction and in the trace-perpendicular direction;

a fourth portion of the trace that starts at an end point of the third portion, that ends at a second point on the trace axis, and that is formed in the trace direction and in a direction opposite the trace-perpendicular direction.

5. The sensor of claim **4**, wherein a width of the trace is between one micrometer and twenty micrometers.

6. The sensor of claim **4**, wherein the sensor grid includes:

additional traces that each have trace axes that are approximately parallel to the trace axis of the trace.

7. The sensor of claim **4**, wherein a length of the fourth portion is at least twice a length of the first portion, the second portion, or the third portion.

8. A projected capacitive touch sensor, comprising:

a sensor grid (a) that includes a trace that (i) has a trace start point and a trace end point, (ii) is electrically conductive between the trace start point and the trace end point, and (iii) is formed in one or more pairs of trace cells that each include a first trace cell and a second trace cell that is rotationally symmetrical to the first trace cell and (b) that includes additional traces that each (i) have trace axes that are approximately perpendicular to a trace axis of the trace and (ii) are radially symmetrical to the trace,

wherein the trace start point and the trace end point define the trace axis,

wherein a trace direction is defined from the trace start point to the trace end point,

wherein a trace-perpendicular direction is defined as being perpendicular to the trace direction,

wherein a segment of the trace that is formed in the first trace cell comprises:

a first portion of the trace that starts at a first point on the trace axis and that is formed in the trace direction and in the trace-perpendicular direction;

a second portion of the trace that starts at an end point of the first portion and that is formed in the trace direction and in a direction that is opposite the trace-perpendicular direction;

a third portion of the trace that starts at an end point of the second portion and that is formed in the trace direction and in the trace-perpendicular direction;

a fourth portion of the trace that starts at an end point of the third portion, that ends at a second point on the trace axis, and that is formed in the trace direction and in the direction opposite the trace-perpendicular direction.

9. The sensor of claim **8**, wherein a width of the trace is between one micrometer and twenty micrometers.

10. The sensor of claim **8**, wherein sensor grid includes:

additional traces that each have trace axes that are approximately parallel to the trace axis of the trace.

11. A projected capacitive touch sensor, comprising:

a sensor grid that includes a trace that (i) has a trace start point and a trace end point, (ii) is electrically conductive between the trace start point and the trace end point, and (iii) is formed in one or more pairs of trace cells that each include a first trace cell and a second trace cell that is rotationally symmetrical to the first trace cell,

wherein the trace start point and the trace end point define a trace axis,

wherein a trace direction is defined from the trace start point to the trace end point,

wherein a trace-perpendicular direction is defined as being perpendicular to the trace direction,

wherein a segment of the trace that is formed in the first trace cell comprises:

a first curved portion of the trace that starts at a first point on the trace axis and that is concave in a direction opposite the trace direction;

a second curved portion of the trace that starts at an end point of the first curved portion and that is convex in a direction opposite the trace direction and in the trace-perpendicular direction;

a third curved portion of the trace that starts at an end point of the second curved portion and that is concave in the trace-perpendicular direction;

a fourth curved portion of the trace that starts at an end point of the third curved portion and that is convex in the trace direction and in the trace-perpendicular direction;

a fifth curved portion of the trace that starts at an end point of the fourth curved portion, that ends at a second point on the trace axis and that is concave in the trace direction.

12. The sensor of claim **11**, wherein a width of the trace is between one micrometer and twenty micrometers.

13. The sensor of claim **11**, wherein the sensor grid includes:

additional traces that each have trace axes that are approximately parallel to the trace axis of the trace.

14. The sensor of claim **11**, wherein the sensor grid includes:

additional traces that each (i) have trace axes that are approximately perpendicular to the trace axis of the trace and (ii) are radially symmetrical to the trace.

15. The sensor of claim **11**, wherein the first curved portion, the second curved portion, the third curved portion, the fourth curved portion, and the fifth curved portion are arcs with a same radius.

16. The sensor of claim **11**, wherein:

the first curved portion, the third curved portion, and the fifth curved portion are arcs with a first radius, and

the second curved portion and the fourth curved portion are arcs with a second radius that is greater than the first radius.

17. The sensor of claim **11**, wherein:

the first curved portion, the third curved portion, and the fifth curved portion are arcs with a first radius.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,958,996 B2
APPLICATION NO. : 15/010086
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INVENTOR(S) : Pedro Luis Fernandes Marques et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page

Column 1 ([*] Notice), Line 3, after “0 days.” delete “days.”;

In the Claims

Column 23, Line 18, Claim 17, delete “radius.” and insert -- radius, and the second curved portion and the fourth curved portion are arcs with a second radius that is less than the first radius. --.

Signed and Sealed this
Thirtieth Day of June, 2020

Andrei Iancu

Andrei Iancu
Director of the United States Patent and Trademark Office